SCIENTIFIC AMERICAN

INFRARED SURVEY TECHNIQUE

SEVENTY-FIVE CENTS

January 1968

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Photomicrograph by Dr. George B. David (original magnification 1,250x, enlarged to 5,000x).

LETTERS

Sirs:

It seems a bit unfair of Professor Williams to use his review of Sir Harold Hartley's *Humphry Davy* [SCIENTIFIC AMERICAN, October, 1967], which he states to be a good book, to promote his own differing views on the style of Davy's work. Williams rejects Hartley's implicit thesis "that Davy's science was purely and exclusively formed from experiments and flashes of insight." Instead he insists that the author should have interpreted Davy as a committed follower of Roger Boscovich's theory of point atoms....

Further, the burden of the available evidence is that Hartley's interpretation of Davy as an empiricist is sounder than Williams' view that he was secretly a metaphysical Boscovichean. Although Williams may not be the only scholar who seriously believes in the Boscovich influence on Davy, I trust that his views on how the historian of science ought to compensate for the lack of supporting evidence are not widely shared.

Allowing for some differences of interpretation, I would agree with Williams that it is "the task of the historian of science ... to re-create the minds of his subjects" from all the available evidence. In this case the evidence consists of about 3,500 pages of Davy's *Collected Works* and several dozen personal and laboratory notebooks. In all of this there are three known references to Boscovich occupying no more than the equivalent of two printed pages.

On the basis of these brief and rather equivocal references, Williams has for several years urged the validity of a strong Boscovichean influence on Davy. He admits that he knows of "no documents ... that provide the essential information" that would show *how* Davy used Boscovichean ideas in his scientific work, but he still asks us to believe it with sufficient conviction to reconstruct Davy's mind in the Boscovichean mold!

On the other hand, Davy's *Collected Works* contain countless warnings against commitment to false hypotheses and hasty generalizations. As he told his Royal Institution audience in 1809, conjecture "except when it has its source in facts, and its termination in experiments, ought to be rejected as dangerous and unprofitable," and he added, "To be attracted to mere speculation is to be directed by a dream."

I agree with Professor Williams that we must attempt to reconstruct the paths by which a creative scientist arrived at his discoveries and inventions, since this is a very important part of "our understanding of this greatest of all human inventions," modern science. But we must temper our desire for understanding with enough discipline to ensure that the understanding we acquire not only is believable but also bears as rigorous a relationship to the evidence as it is possible to establish. History is not so different from science that it can invent freely in the absence of the hoped-for facts....

I wish Professor Williams would give up his dream of a direct line of influence from Boscovich through Davy to Faraday, because it is not adequately supported. His persistent urging of this tenuous conjecture has already caused it to be mistaken for historical truth, and ought now to be "rejected as dangerous and unprofitable."

ROBERT SIEGFRIED

The Royal Institution
London

Sirs:

I fail to see anything methodologically reprehensible in seizing on Davy's admittedly rare references to Boscovich. Surely Professor Siegfried's peculiar quantitative criterion is irrelevant. When a man goes to the trouble to reveal his fundamental ideas on the nature of matter, to provide his readers with an exact source of these ideas and then to describe the work in which these ideas appear as his last philosophical will and testament, is it asking too much of the historian that he pay some attention? Does Davy's scientific work make sense within the Boscovichean framework? We shall certainly never know if no one looks.

There is another point that seems to me to be of central importance. There is a world of difference between speculation in science and in history. In science lack of evidence ultimately destroys the speculation; in history this is not always true, since the evidence may have been destroyed by fortuitous events. The value of historical speculation is not to provide a guide for the search for evidence but, rather, to give a coherence, a depth and a unity that a mere reporting of facts cannot provide. This kind of speculative interpretation is a commonplace in the writing of history. My essay was addressed to those who write the history of science without having had the benefit of rigorous training in history in the belief that the history of science can only benefit from contact with general history. Professor Siegfried's letter reinforces my belief.

L. PEARCE WILLIAMS

Department of History
Cornell University
Ithaca, N.Y.

Sirs:

Some corrections of a paragraph or two of Charles F. Hockett's review of *Biological Foundations of Language* [SCIENTIFIC AMERICAN, November, 1967] are obviously called for:

1. Noam Chomsky, described as a "neomedieval philosopher" in the review, is also among other things a professor of modern languages at the Massachusetts Institute of Technology, in which capacity one would think he would be perfectly fitted to advise the author of this book. The "tragedy" of which the reviewer melodramatically speaks in this connection must mean, if anything, that the author consulted one kind of linguist rather than another, but there is very little to be made of that unless one has some private quarrel with the leader of the M.I.T. school.

2. The account we are given by the

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THE COVER

The photograph on the cover shows a portion of the San Pablo reservoir near Berkeley, Calif., as recorded on a film that is sensitive to infrared energy. The technique is designed to enhance the ability of an experienced interpreter to identify the natural resources that appear in such a photograph (see "Remote Sensing of Natural Resources," page 54). Like other color film, this film has layers dyed blue, green and red. The blue and green layers respond to wavelengths in the visible-light portion of the spectrum: the blue to green light and the green to red light. The red dye responds to wavelengths of between .7 and .9 micron in the very near infrared portion of the spectrum. The effect is that the infrared energy of highest intensity produces the brightest reds in the photograph. Little infrared energy is reaching the camera from areas that appear blue in the photograph. The San Pablo reservoir area is a test site used by the National Aeronautics and Space Administration in its Earth Resources Program to determine what kind of "tone signature" is produced on different kinds of film by known resources, such as the various trees in the photograph. With data thus established from areas with known resources, NASA hopes that resources can be identified in other areas by remote sensing from airplanes or spacecraft.

THE ILLUSTRATIONS

Cover photograph by Air-Photo Company, Inc.

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DEPARTMENTS

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reviewer of Chomsky's "weird notions" narrows his whole contribution to American linguistics down to the one question of mentalism, which is dismissed in a paragraph, as if, having got rid of this aberration, one could henceforth forget about the rest of Chomsky's work. As is well known, mentalism is something that most Bloomfieldians will not talk about, because it seems they cannot even think about it, but no reader of your magazine should be left with the impression that Chomsky's philosophical preoccupations are such that they have somehow prevented him, as the reviewer suggests, from accounting for the "empirical evidence" of language. A glance at his work on syntax and more recently phonology will correct this misimpression, which the reviewer has tried to foster by making Chomsky out to be an ordinary-language philosopher rather than a linguist of any description.

3. Lastly, anyone who has heard, however dimly, the uproar raised over the methods and results of the M.I.T. school of linguistics—and an echo of this is sounded through Professor Hockett's review—must smile to hear in these distracted days of "our calm and quietly growing tradition of scientific linguistics." So the faithful caretakers of the Bloomfieldian tradition may speak, but meanwhile it is high time that at least an accurate report of what is going on in the embattled camp on the other side were forthcoming from the pages of your magazine.

FREDERIC AMORY

Department of English
Mills College
Oakland, Cal.

ERRATUM

An illustration in the article "The Climate of Cities" (SCIENTIFIC AMERICAN, August, 1967) gave the impression that temperatures rose during the night as recorded in traverses through northeast London. In the illustration, which is on page 23, the solid black line should have been a broken one, and vice versa. The temperature traverses and the findings depicted in the top illustration on page 22, relating to loss of sunshine in London, were the work of T. J. Chandler of University College London.

SCIENCE/SCOPE

"The perfect Surveyor mission" is the accolade the project team gave Surveyor VI, which had returned more than 30,027 pictures of best-yet quality when it was shut down for the lunar night that began November 24. Soft-landing within four miles of its midcourse target on crater-pocked Central Bay, almost in the center of the moon's visible face, Surveyor VI completed NASA's survey of potential astronaut landing sites.

Surveyor VI was relaunched November 17, becoming the first spacecraft ever launched from another heavenly body. The three vernier engines burned only 2½ seconds and exerted 150 pounds of thrust to lift the 616-lb. spacecraft 10 feet and move it laterally 8 feet.

Four new shipboard radar-computer systems --three of them earmarked for warships of the Federal Republic of Germany -- were delivered recently to the U.S. Navy. Used on guided-missile ships, the advanced systems scan the sky with a high-frequency, narrow pencil beam to determine target's height, range, and bearing. Three systems built under an earlier contract are already operational on Australian destroyers, and others are being installed on U.S. destroyers.

From its synchronous station above the Amazon, NASA's Applications Technology Satellite III has successfully carried out several major experiments. Its "spin-scan" camera (developed by Santa Barbara Research Center, a Hughes subsidiary) is returning high-resolution color photos of the earth's full face. Their accurate color will make it possible to determine height of clouds, width and location of ocean currents, and moisture content of soil.

The mechanically despun antenna aboard ATS-III is receiving signals from earth 10 times more effectively than antennas presently used on communications satellites. Its new VHF transponder is providing high quality two-way radio communications between ground stations and aircraft thousands of miles apart.

Two satellite communications ground stations will be built by Hughes in South America, one for Peru, the other for Brazil. They will be used to broadcast and receive international telephone calls, television, and other telecommunications. Initial capacity will be sufficient to handle 120 two-way transatlantic phone calls, plus television, through one or more Intelsat satellites.

New commercial products from Hughes: a broadband high-power pulsed traveling-wave tube by the electron dynamics division; it has 40% efficiency at the 25-30kw level in X-band, and is the only commercially available TWT in X-band offering both cross-field amplifier efficiency and TWT gain....an expanded line of MOS products at Hughes/Newport Beach, which recently acquired Raytheon's line of metal-oxide silicon (MOSFET) discrete devices and integrated circuits.

Bone sections from fish ears
reveal the age of the fish
and the population of coastal waters.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY, 1918: "It is probable that when the history of the world war comes to be written, the year 1917 will be named the most dramatic of the war—unless indeed the opening year of the war be so designated. The first of the great dramatic happenings of the year was the startling Russian revolution. The collapse of Russia has enabled the Teutons to throw their whole strength against the western line. The first result of this was seen in the collapse of the Italian armies and their retreat to the Piave River, where the issue of battle is yet in the balance. The absolute certainty of German defeat is found in the other great dramatic happening of the year—namely the entry of the United States into the war on April 6, 1917. The months which must elapse before the American army reaches the front in sufficient force seriously to affect the situation will witness the most critical and fierce fighting of the whole war, for unquestionably Germany will make a last supreme effort to regain the initiative and break through the western front."

"The radioactivity of meteorites, a subject hitherto almost completely neglected, is discussed by Messrs. J. T. Quirke and L. Finkelstein in a recent number of the *American Journal of Science*. The writers determined by an ingenious method of analysis the radium content of 22 meteorites of various types, furnished by the Field Museum of Natural History. The results appear to show that the average stony meteorite is considerably less radioactive than the average igneous rock, and probably less than one-fourth as radioactive as an average granite; also that metallic meteorites are almost free from radioactivity."

"One of the surprises of the present war has been the great explosive power of tri-nitro-toluene, better known under its abbreviated form of T.N.T. The explosive used in the Boer War was principally lyddite, and the basis of this and many other similar explosives was picric acid. T.N.T. is the next step upward in the same chemical series. The power of the modern torpedo, which has had so great an effect on naval tactics, is due to T.N.T., and probably much of the high explosives used to pulverize trenches and dugouts and create the great shell-craters consists of the same substance."

"One of the most notable events of the past year has been the installation of the great telescope on Mt. Wilson. This is a 100-inch reflector—by far the largest in the world. The mounting of the telescope has been under construction for several years and was much delayed by the war. The parts were so large that they required the machinery of a shipyard for their construction. The telescope is mounted in a dome 100 feet in diameter and 100 feet high. The hauling of the huge glass mirror and of the heavy sections of the telescope mounting up the steep mountain road to the summit of Mt. Wilson, 6,000 feet high, and the erection of the mammoth but highly sensitive instrument without mishap was an engineering accomplishment of no small importance."

SCIENTIFIC AMERICAN

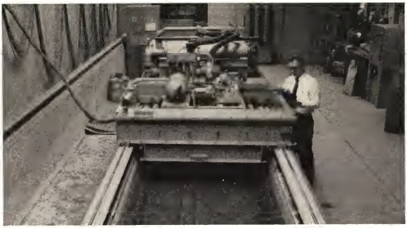
JANUARY, 1868: "It has been announced that the Suez Canal is in such an advanced stage of completion that already an English vessel has passed through to the Red Sea. It appears that the vessel was a Government tug-boat, which was to assist in the embarkation of the Indian troops at Suez, and that after being lightened as much as possible even to the removal of the paddle wheels, a number of empty casks were placed under her, and in this manner she reached Suez."

"Mr. R. W. Thompson, C.E., Edinburgh, has invented and patented a new locomotive for common roads, which was lately tried in the neighborhood of Edinburgh. The tires are made of bands of vulcanized india-rubber, about 12 inches wide and five inches thick. Incredible as it may appear, this soft and elastic substance not only carries the great weight of the road steamer without injury but also passes over newly broken road, metal, broken flints and all kinds of sharp things without leaving even a mark on the india-rubber. The tires do not sink into the road in the least degree. They pass over stones lying on the surface without crushing them. The bite on the road is something marvelous,

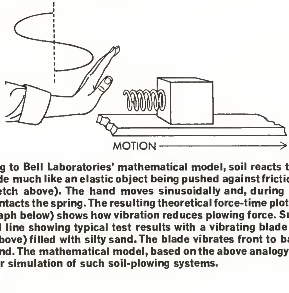
Report from

BELL LABORATORIES

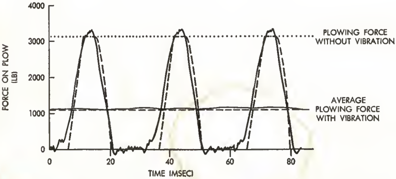
Equations for plowing



Soil dynamics laboratory at the Bell Telephone Laboratories location in Chester, N. J. Test soils of various kinds are placed in the long bin (foreground). A plow blade, not visible in this photo, rides under the carriage frame. The blade can be vibrated over a wide range of frequencies and amplitudes as the carriage is driven along the length of the bin.



According to Bell Laboratories' mathematical model, soil reacts to a vibrating plow blade much like an elastic object being pushed against friction over a surface (sketch above). The hand moves sinusoidally and, during part of each cycle, contacts the spring. The resulting theoretical force-time plot (dashed line in the graph below) shows how vibration reduces plowing force. Superimposed is a solid line showing typical test results with a vibrating blade in a test bin (photo above) filled with silty sand. The blade vibrates front to back 30 times per second. The mathematical model, based on the above analogy, has allowed computer simulation of such soil-plowing systems.



It has long been known that vibrating a plow blade makes it easier to force through soil. But what kind of vibration is most effective? That is, how much power should be applied to the blade and in what manner should the blade be vibrated?

We at Bell Telephone Laboratories are accumulating considerable information on this subject because we need a small, highly efficient plow that will bury telephone wires across lawns and up to houses with minimum drawbar pull. Unlike agricultural plows, which are built for maximum disturbance of the earth, Bell System plows must bury cable and wires with least possible marring of the property.

Recently, this work has been aided by a mathematical model of plow blade-soil interaction. Bell Laboratories engineers R. J. Boyd and C. L. Nalezny found that forcing a vibrating blade through the ground is analogous to pushing periodically on a spring, attached to a block on a frictional surface (left).

This simple model has helped us design a prototype plow that buries telephone wires two feet deep at speeds up to 75 feet per minute. With most of its power applied to the blade, it can cut through rocky soil and tree roots where conventional machines might stall.

TV special in X-ray room B

This radiologist, using a TV monitor, is viewing an X-ray image of Jimmy's heart 5,000 times brighter than that displayed by a standard fluoroscopic screen. What makes the difference? An X-ray image intensifier tube that is lifting fluoroscopy out of the dark ages and lighting the way for doctors to use revolutionary new techniques.

Today, heart specialists can accurately position cardiac catheters within the heart chamber to pinpoint defects and provide precise diagnosis. Using a similar technique, other specialists can examine in detail the function of the kidneys and other vital organs. Orthopedic surgeons can actually see fractures being set. Even routine procedures, such as gastro-intestinal examinations, are improved by the radiologist's ability to see a brighter image.

FIGURE I — TYPICAL SYSTEM USING TV MONITOR

The red goggles are gone

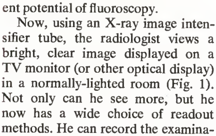
As recently as eight years ago, a radiologist preparing to fluoroscope a patient donned red goggles at least twenty minutes in advance of the examination to adapt his eyes to the darkened fluoroscopic room. Even then, his vision was so limited that images on the fluoroscopic screen appeared dim and hazy. Thus, he was unable to make full use of the inherent potential of fluoroscopy.

Now, using an X-ray image intensifier tube, the radiologist views a bright, clear image displayed on a TV monitor (or other optical display) in a normally-lighted room (Fig. 1). Not only can he see more, but he now has a wide choice of readout methods. He can record the examination on motion picture film or video tape for later consultation or review. And, for training and remote, instantaneous consultation, he can feed the display to other locations via closed circuit TV.

How an X-ray image intensifier works

X-rays emerging from the patient's body pass through the input end of the tube (Fig. 2) and strike a glass plate coated on one side with an X-ray sensitive, zinc-cadmium-sulfide phosphor.

FIGURE 2 — SCHEMATIC DIAGRAM OF X-RAY IMAGE INTENSIFIER TUBE



These rays, attenuated in varying degrees by the portion of the body they have just penetrated, cause the phosphor to fluoresce in a pattern identical to that of the penetrated structure. Light from the fluorescing phosphor then strikes a photocathode layer on the opposite side of the glass plate causing it to emit electrons in a similar pattern. These electrons are accelerated and focused on a small phosphor screen at the output end of the tube. The output screen converts the electron beam into a small light image which is 5,000 times brighter than the original X-ray image on the input screen.

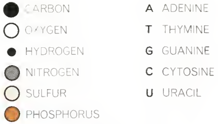
This phenomenal gain in brightness is accomplished in three separate ways: First, the photocathode is a highly efficient converter of light energy. Second, the energy of the electrons from the photocathode is increased by the application of high voltage to the anode. And, finally, reduction of the image greatly increases the brightness.

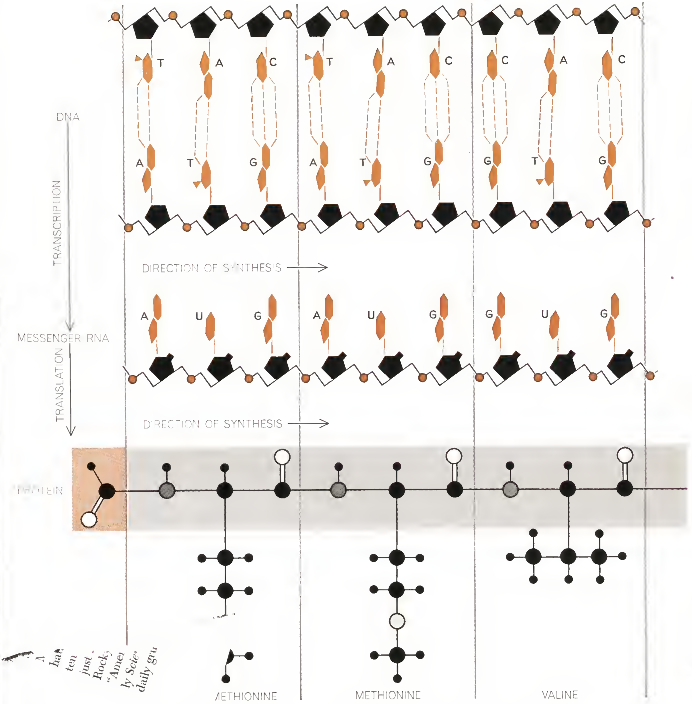
These image intensifier tubes are produced by Machlett Laboratories, a Raytheon subsidiary and the world's largest manufacturer of X-ray tubes. The same basic technology is being applied to enable our soldiers to see in the dark and may someday find widespread use in industry and in everyday life.

This is typical of how Raytheon is finding better ways to serve people and the nation . . . in space and defense systems, and in such commercial areas as natural resources exploration, education, home appliances, components, marine electronics and communications. Raytheon Company, Lexington, Massachusetts.

RAYTHEON

Using extracts from the *E. coli* bacterium, we were studying the chemical characteristics of the combination of the amino acid methionine with its specific tRNA. In the course of this study we decided to investigate the breakdown of the compound by pancreatic ribonuclease, an enzyme known to split RNA chains at certain specific bonds [*see top illustration on page* 39]. In order to facilitate identification of the products we labeled the methionine in advance with radioactive sulfur, and after treatment of the methionine-tRNA compound with





TRANSMISSION OF GENETIC INFORMATION takes place in two main steps. First the linear code specifying a particular protein is transcribed from deoxyribonucleic acid (DNA) into messenger ribonucleic acid (RNA). The code letters in DNA are the four bases adenine (A), thymine (T), guanine (G) and cytosine (C). Hydrogen bonds (*broken lines*) between the complementary bases A–T and G–C hold the two strands of the DNA molecule together. The strands, which run antiparallel, consist of alternating units of deoxyribose sugar (*pentagons*) and phosphate (PO_3H). The code letters in messenger RNA duplicate those attached to one strand of the DNA except that uracil (U) replaces thymine. In RNA the sugar is ribose. In the second step of the process messenger RNA is translated into protein. The code letters in RNA are read in triplets, or codons, each of which specifies one (or sometimes more) of the 20 amino acids that form protein molecules. It has now been found that the codon AUG can specify a modification of methionine known as formyl methionine, which signals the start of a protein chain. Inside the chain AUG specifies ordinary methionine. The codon GUG, which codes for valine inside the chain, can also specify formyl methionine and initiate chain synthesis.

the enzyme we separated the products by means of electrophoresis, the technique that segregates electrically charged molecules according to their charge, size and shape. As was to be expected, one of the products was the compound known as methionyl-adenosine, a combination of methionine with the terminal adenosine portion of the tRNA molecule. But we also found, to our surprise, that the products included a considerable amount of a formylated variety of this compound, that is, a variation in which a formyl group (CHO) replaced a hydrogen atom in the amino group (NH_2) of the molecule. It turned out that this was by no means an artifact of the treatment to which the original compound had been subjected; growing cells proved to contain a high proportion of formylated methionine tRNA.

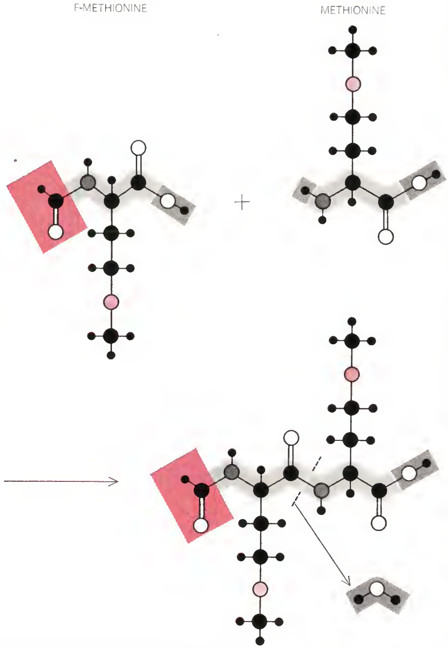
It was immediately evident that formylated methionine must occupy a special position in the protein molecule. The attachment of the formyl group to the amino group would prevent the amino group from forming a peptide bond [*see illustration below*]. Consequently the formylated amino acid must be an end unit in the protein molecule. Since an amino group forms the "front" end of protein molecules when they are being assembled, formylated methionine must constitute the initial unit of the molecule.

We were able to separate the methionine tRNA of *E. coli* into two distinct species, and found that only one can be formylated. The formylatable species constitutes about 70 percent of the bacterium's methionine tRNA [*see bottom illustration on opposite page*]. Recent work in our laboratory at the Medical Research Council in Cambridge has established that the compound is formylated (at methionine's amino group) only after the amino acid has become attached to the tRNA molecule. The donor of the formyl group is 10-formyl tetrahydrofolic acid, and the reaction is catalyzed by a specific enzyme that acts exclusively on the combination of methionine with the formylatable species of tRNA.

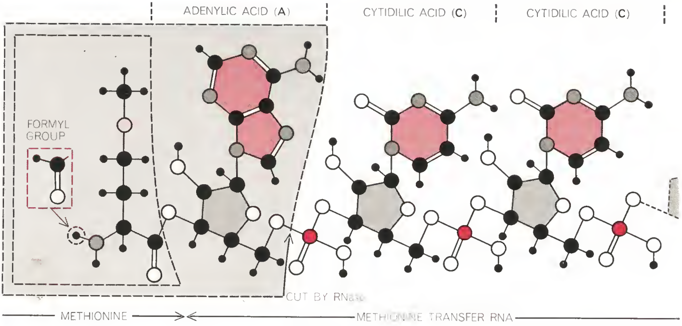
Our laboratory and others have proceeded to analyze the initiation of protein formation by several experimental techniques. We began by testing a number of different synthetic messenger RNA's for their ability to bring about synthesis of a polypeptide incorporating methionine. Only two of the synthetic polynucleotides we tried proved to be capable of doing this. One contained the bases uracil, adenine and guanine (poly-UAG); the other had only uracil and guanine (poly-UG). We found that in a mixture of amino acids and other cell-free materials where only the formylatable species of methionine tRNA was present, either poly-UAG or poly-UG would cause the synthesis of a polypeptide with methionine in the starting position—and only in that position. Surprisingly, this was true even when no formyl group was attached to the methionine-tRNA compound. We had to conclude that the formylatable version of the tRNA for methionine possessed a special adaptation that helped it to function as a polypeptide-chain initiator.

A thorough search was made for formylated varieties of other tRNA's: that is, of tRNA's for amino acids other than methionine. None were found. This raised an interesting question. In the proteins produced by *E. coli* cells the amino acid at the "front" end of the protein molecule is not always methionine; often it is alanine or serine. These amino acids are never found to be formylated. How, then, does either of them become the initial member of the protein chain?

Experiments with natural messenger RNA's (rather than synthetic polynucleotides) have suggested an explanation. Jerry Adams and Mario Capecchi, work-

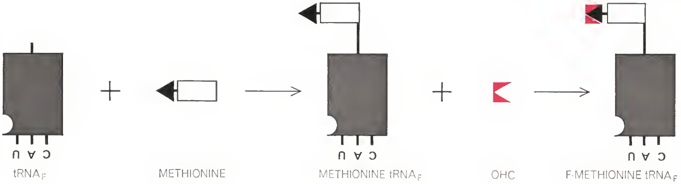


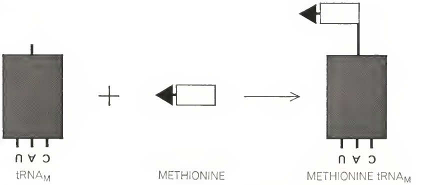
FORMYL METHIONINE, abbreviated F-Met, has a formyl group (CHO) where methionine (Met) has a hydrogen atom as part of a terminal amino (NH_2) group. When an amino acid enters a protein chain, one of the hydrogens from the amino end of one molecule combines with an OH group from the carboxyl (COOH) end of another molecule to form a molecule of water. The two molecules are then linked by a peptide bond. The formyl group prevents this reaction, hence F-Met can appear only at the beginning of a protein chain.



TRANSFER OF AMINO ACID to the site of protein synthesis is accomplished by molecules of transfer RNA (tRNA). There is at least one species of transfer RNA for each amino acid. All transfer RNA molecules contain the base sequence CCA at the terminal that holds the amino acid. Such a terminal is diagrammed here and shown coupled to methionine. Methionine that subsequently can be converted to formyl methionine is transferred by a different tRNA. When treated with the enzyme ribonuclease (RNase), the final base (adenine) and its coupled amino acid are split off from the rest of the transfer RNA. The fragment is called an aminoacyl adenosine.

ing in the laboratory of James D. Watson at Harvard University, and Norton D. Zinder and his collaborators at Rockefeller University have used messenger RNA's extracted from bacterial viruses. These RNA's direct the synthesis of the proteins that form the coat of the virus. The experimenters in Watson's and Zinder's laboratories found that when such an RNA was added to cell-free materials in the test tube, formylated methionine turned up at the starting end of the coat proteins that were synthesized. This was most surprising, because normally in living systems the initial amino acid of the viruses' coat protein is alanine. A significant clue was found, however, in the fact that the coat proteins synthesized in the cell-free systems invariably had an alanine in the second position, following the formyl methionine. From this it seems reasonable to deduce that in living systems, as in the cell-free system, the formation of the protein starts with formyl





TWO METHIONINE tRNA's, designated $tRNA_F$ and $tRNA_M$, exhibit different characteristics. In the presence of an energy source (adenosine triphosphate) and a special coupling enzyme, both tRNA's combine with methionine. Only $tRNA_F$, however, forms a complex that is recognized by another enzyme that can convert methionine to formyl methionine. The formyl group is provided by 10-formyl tetrahydrofolic acid. The complex that results is F-Met-$tRNA_F$.

tRNA	CODONS
MET-tRNA$_M$	AUG
MET-tRNA$_F$ / F-MET-tRNA$_F$	AUG, GUG

CODON ASSIGNMENTS show the bases in messenger RNA that cause the two Met-tRNA's to deliver methionine or formyl methionine for insertion in a protein chain.

methionine, and that the bacterial cells supply an enzyme that chops off the formyl methionine later, leaving alanine in the first position.

Experiments with *E. coli* RNA in our laboratory and others have produced similar results. Messenger RNA extracted from these bacteria, like that extracted from bacterial viruses, causes cell-free systems to synthesize proteins with formyl methionine in the first position. On the other hand, the proteins extracted from living *E. coli* cells usually have unformylated methionine or alanine or serine in the lead position. It therefore seems likely that the living cells remove the formyl group from methionine or split off the entire formyl methionine unit after synthesis of the protein chain has got under way. The significance of the frequent appearance of alanine and serine at the front end of *E. coli* proteins is not clear; no satisfactory explanation has yet been found for the cell's selection of alanine and serine to follow formyl methionine. At all events, what does seem plausible now is that in *E. coli* the synthesis of all proteins starts with formyl methionine as the first unit.

How does the messenger RNA convey the message calling for formyl methionine as the starting unit? Does it use a special codon addressed specifically to the formylatable variety of methionine tRNA? We tested various codons for their ability to bring about the delivery of formyl methionine to the protein-synthesizing ribosomes. A codon for methionine was already known: it is AUG. We found that AUG was "read" by both varieties of methionine tRNA—the formylatable and the unformylatable. Either variety of tRNA delivered and bound methionine to the ribosome in response to AUG. We found that the formylatable tRNA (but not the other variety) also recognized and responded to another codon: GUG.

These findings were consistent with our earlier observation that either poly-UAG or poly-UG could effect the incorporation of methionine into a polypeptide in a cell-free system. Poly-UAG, of course, can contain the codons AUG and GUG, depending on the sequence in which the bases happen to be arranged in this polynucleotide; poly-UG provides the codon GUG. That both AUG and GUG can initiate the synthesis of a methionine polypeptide was confirmed and clearly spelled out in detail by experiments in the laboratory of H. Gobind Khorana at the University of Wisconsin. Using synthetic messenger RNA's in which the bases were arranged only in these triplet sequences (AUG and GUG), Khorana's group showed that both codons led to the formation of a chain with formyl methionine in the starting position. AUG also placed methionine in internal positions in the chain, but GUG, which can code only for the formylatable version of the tRNA, incorporated methionine only at the starting end [*see illustration below*].

Investigators in the laboratories of Severo Ochoa at New York University and Paul M. Doty at Harvard obtained the same results. They also noted that both codons possess a certain versatility as signals, depending on their location in the messenger RNA. Located at or near the beginning of the messenger RNA chain, the AUG triplet is recognized by the formylatable variety of tRNA and leads to the placement of formylated methionine at the starting end of the polypeptide; farther on in the messenger RNA chain the same triplet is recognized by unformylatable tRNA and causes the placement of unformylated methionine in the internal part of the polypeptide. In short, at the "front" end of the RNA message the AUG codon says to the cell's synthesizing machinery, "Start the formation of a protein"; when it is located internally in the message, AUG simply says, "Place a methionine here." Similarly, the codon GUG was found to have two possible meanings: located at the beginning of the message, it orders the initiation of a protein with formylated methionine; in an internal position in the message it is the code word for placement not of methionine but of the amino acid valine.

How is it that each of these codons signifies a starting signal in one position and has a different meaning in another? Obviously this question will have to be answered in order to clarify the language of the protein-starting mechanism. Indeed, we cannot be sure that a codon in itself constitutes the entire message for the initiation of a protein. The signaling mechanism may be more complex than one might assume from the findings developed so far. Those findings are based almost entirely on work done with artificial messenger RNA's, and it is possible that the messages they provide are only approximations—meaningful enough to stimulate the cell machinery but not the full story.

When we consider how important the

SYNTHETIC MESSENGER	SOURCE OF METHIONINE		POSITION OF METHIONINE IN POLYPEPTIDE		CODONS USED
	MET-tRNA$_M$	MET-tRNA$_F$ / F-MET-tRNA$_F$	INTERNAL	N-TERMINAL	
RANDOM POLY-UG	–	+	–	+	GUG
RANDOM POLY-AUG	+	+	+	+	AUG, GUG
POLY-(UG)$_n$	–	+	–	+	GUG
POLY-(AUG)$_n$	+	+	+	+	AUG

INCORPORATION OF METHIONINE in protein-like chains has been studied with synthetic messenger RNA's and the two species of methionine transfer RNA: $tRNA_M$ and $tRNA_F$. The plus sign indicates combinations that lead to incorporation. In random poly-UG and random poly-AUG the bases can occur in any sequence, but presumably the only effective sequences are GUG and AUG. Poly-$(UG)_n$ and poly-$(AUG)_n$ are synthetic chains of RNA consisting of 30 or more repetitions of the base sequences indicated.

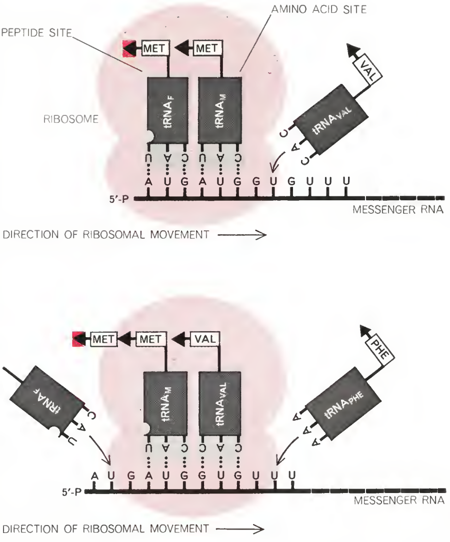
codons AUG and GUG are in initiating the synthesis of polypeptides, it is certainly odd that a synthetic messenger RNA such as poly-U, which of course cannot supply those codons, nevertheless manages to cause the ribosomes to produce a polypeptide. We can only conclude that they do so by mistake, so to speak, that is, by acting in a way not entirely specified by the available information. (It is ironic that the genetic code was broken because artificial systems were able to make the right kind of mistake!) Are there circumstances that tend to assist these systems in accomplishing proper mistakes? One influential factor has been found. It is the concentration of magnesium in the cell-free system of building materials. A high magnesium concentration makes it possible for many kinds of synthetic messenger RNA to generate polypeptides; when the magnesium concentration is lowered, only the RNA's that contain AUG or GUG succeed in doing so. What magnesium may have to do with polypeptide initiation is still unclear.

Let us come back to the placement of the initial methionine as the normal first step in the construction of a protein. We have noted that the methionine-tRNA complex that places the amino acid in the initial position does not necessarily contain a formyl group. Evidently under conditions of a relatively high concentration of magnesium the formyl group of itself plays no essential role in the installation of the amino acid. What seems to be important is the character of the tRNA: only the formylatable variety of methionine tRNA can initiate the synthesis, and it can do so even when it is not formylated. What, then, are the specific properties that account for its role as an initiator?

A reasonable supposition is that this variety of tRNA has a special shape or configuration that helps it to fit into a particular site on the ribosome. As a matter of fact there is evidence that ribosomes possess two kinds of site for the attachment of tRNA's. One kind, called an amino acid site, simply receives and positions the tRNA when it arrives with its amino acid; the other kind, called a peptide site, holds the tRNA while a peptide bond is formed between its amino acid and an adjacent neighbor [*see illustration at right*]. It is therefore plausible to suppose that the formylatable variety of the tRNA for methionine may have a shape that helps it to fit into a peptide site on the ribosome and thus be in a position to start the linking together of amino acids.

Evidence in support of this hypothesis has been obtained in our laboratory by Mark S. Bretscher and one of us (Marcker) and by Philip Leder and his associates at the National Institutes of Health in experiments using the antibiotic puromycin. The structure of puromycin is similar to that of the end of a tRNA molecule that attaches to an amino acid [*see illustration on next page*]. Because it has an NH_2 group, puromycin can form a peptide bond with an amino acid, but since it lacks the free carboxyl (COOH) group of a normal amino acid it cannot form a second peptide bond. Thus it cannot participate in chain elongation. Various experiments indicate that puromycin will add on to—and terminate—a growing polypeptide chain only when the tRNA holding the chain is bound in the peptide site.

In other experiments it has been found that the formylatable variety of methionine tRNA, when bound to a ribosome, will combine with puromycin; the unformylatable variety of the tRNA, on the other hand, will not react with puromycin. The experimental results therefore indicate that there are indeed two kinds of ribosomal site or state: one where a



PROTEIN SYNTHESIS takes place on cellular particles called ribosomes, which travel along the "instruction tape" of messenger RNA, reading off the genetic message. The ribosome evidently has two sites for accommodating molecules of transfer RNA: a peptide site and an amino acid site. It appears that the structure of tRNA$_F$ enables it to go directly to the peptide site, thereby initiating the protein chain. This special structure is symbolized by a notch in tRNA$_F$. Other tRNA's may acquire the configuration needed for the peptide site after first occupying the amino acid site. In step 1 (*top*) the codon AUG at the front end (5′-phosphate end) of messenger RNA pairs with the anticodon CAU that is believed to exist on tRNA$_F$, which delivers a molecule of formyl methionine to start the protein chain. The codon AUG in the second position is paired with the CAU anticodon of tRNA$_M$, which delivers a molecule of ordinary methionine. In step 2 (*bottom*) the tRNA$_F$ molecule has moved away and the peptide site has been occupied by tRNA$_M$, which is now coupled to the growing protein chain. Valine transfer RNA has moved into the amino acid site.

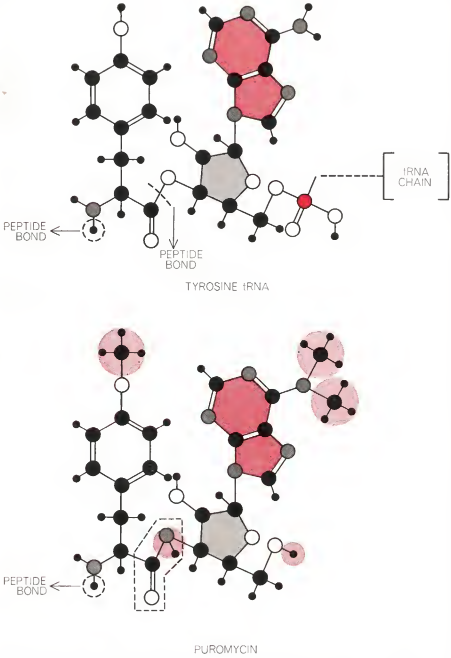
peptide bond cannot be formed between the peptide chain and puromycin and one where it can. Most likely the latter is the peptide site. Furthermore, the experiments have strengthened the suspicion that the formylatable tRNA possesses a unique structure that somehow helps it to move into the peptide site on a ribosome. Apparently the structure of the formylatable tRNA has been particularly tailor-made for its function as a chain initiator.

The question therefore arises: What is the precise role of the formyl group? If the formyl group per se has nothing to do with placing methionine in the starting position, what function does it have? Our earlier experiments, in which we used a relatively high magnesium concentration, suggested that the formyl group is involved somehow in the formation of the first peptide bond, which launches the building of the polypeptide chain. When the methionine tRNA complex is formylated, synthesis of the polypeptide proceeds much faster than when it is not. This effect can be ascribed to the fact that the presence of the formyl group somehow facilitates the entry into the peptide site. It still remains to be determined just how the formyl group helps to promote such an effect.

Further light has been shed on the problem of protein-chain initiation in the past year by the work of several laboratories, including our own. Special protein agents, still poorly defined, have been implicated together with a cofactor in the formation of the initiation complex on the ribosome. When these new components are present and the supply of magnesium is low, the formyl group is necessary if the formylatable methionine tRNA is to be attached to the ribosomal peptide site by a messenger. Quite recently the cofactor has been identified as being a nucleotide derivative: guanosine triphosphate. Hence we are coming to the view that the conditions prevailing within the living cell are approached by these low-magnesium conditions, where there is strict specificity for forming the initiation complex and for unambiguous polypeptide formation. In our present state of knowledge, however, it is still unclear how these new components help to ensure the placement of the formylated methionine tRNA in the peptide site on the ribosome.

The specific findings concerning the initiation of protein synthesis that we have discussed in this article apply only to bacterial cells. So far no such form of tRNA (containing the formyl group or any other blocking agent) has been found in the cells of mammals. Accordingly the mechanism of protein-chain initiation is possibly different in mammalian cells from the mechanism discussed here. The process of polypeptide initiation in the cells of higher organisms is currently under study in several laboratories.

Meanwhile the investigation of the *E. coli* system is being pursued with experiments that promise to yield further insights. The way in which the vaguely characterized protein agents and guanosine triphosphate are involved in the initiation of a polypeptide chain is being explored. Much work is under way on analyzing the sequence of nucleotides in natural messenger RNA's, with a view to determining whether or not AUG or GUG constitutes a complete coding signal for protein initiation. We are searching for differences between the formylatable and unformylatable varieties of methionine tRNA, in their nucleotide sequences and in their three-dimensional structures, that may throw light on their respective interactions with the ribosomes.



PROTEIN-CHAIN TERMINATION can be induced by adding puromycin, an antibiotic, to a protein-synthesizing system. The structure of puromycin closely resembles the structure formed by the amino acid tyrosine and the terminal base of tRNA. Colored disks mark the atomic differences. Tyrosine can be inserted in a protein chain because it can form two peptide bonds. Puromycin can form only one peptide bond because the —CONH— linkage (*inside broken line*) is less reactive than the —COO— linkage in tyrosine tRNA.

The hope of doing each other some good prompts these advertisements

Kodak

The education market

In addition to the very bright and fictitious young man with whom we exchange correspondence below, we know a very real and alert young citizen from the center of our city who can scarcely read the simplest words, though she is almost 9. It comes so hard because in the lives of the parents she loves and who surely love her, reading and writing play hardly any part. That leaves only school to give these capabilities interest and importance. Philosophical argument won't sway Helen but something had better work.

Some 80 kids from Helen's part of town are bussed 20 miles east each morning to join the other pupils in the Demonstration School of State University College at Brockport. The Demonstration School serves its usual functions in a teacher-training institution and is furthermore examining approaches to prepare suburban educators for integrated education. Troubles with reading as bad as Helen's can turn up in college faculty offspring, even if differently caused.

An office in the Demonstration School is occupied this academic year by a man who is on the payroll not of the State University of New York but of the Kodak Research Laboratories, which have been concentrating for the past 55 years almost exclusively on the application of chemistry and physics to photography. It is a strange move on our part, isn't it? The man has been instructed to observe new educational concepts at work and find projects where Kodak's resources might be further utilized in solving the present-day problems of education. We hope he finds some.

* * * * *

Two other men from the Kodak Research Laboratories have successfully completed a more familiar and easier project. They have announced discovery of a new screen material that makes projected images at least six times brighter than screens currently available. Remarkable changes can be effected in the microstructure of certain sheet aluminum alloys to deliver the high reflectance only in the solid angle wanted.

* * * * *

An ad that has just appeared in a teachers' magazine says "... Brighter than you can imagine. We call it the KODAK Projection SUNSCREEN. Leave room lights on, windows uncovered, and still watch sharp, bright movies. There'll be no more squirming and giggles in the dark. This high-intensity screen makes both color and black-and-white movies absolutely brilliant. It's built into the cover of every KODAK EKTAGRAPHIC 8 and Sound 8 Projector. For details, write for Bulletins V3-8 and V3-9 [to Eastman Kodak Company, Motion Picture and Education Markets Division, Rochester, N.Y. 14650]."

* * * * *

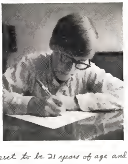
The question still remains: will Helen learn to care about the difference between "MEAT" and "BEAT"?

Doesn't everybody know this?

Although KODACHROME Film and EKTACHROME Film in 135, 126 (such as you need for the KODAK INSTATECH Close-Up Camera) and roll film sizes are primarily for processing to color slides, we also offer a service in making color prints and enlargements from them in sizes up to 11 x 14".

On the other hand. KODACOLOR-X Film in these same camera sizes is primarily for prints and enlargements. If you like what you see in the prints, we can make you projection-mounted slides from any of them.

The various options quickly grow most complex, but it seems to be something of a service to remind you that they exist. It is our earnest hope that the dealer will do a good job of explaining them if you should find a need to take an interest in the subject.



Eastman Kodak Company
Rochester, N.Y.

Dear Sirs:

In only 7 years hence I expect to be 21 years of age and it will be legal for me to engage in investment and speculation without consent. I am now preparing for that time. It is therefore necessary for me to have certain information about scientific developments that will take place. As I have been interested in photography I would like to know what plans you have for bringing out new kinds of films to work with laser light instead of plain light. I also happen to understand how cathode-ray tubes work and would like to know why you don't make film where the electron beam works right on the film instead of making light on the tube face and then photographing that.

Yours very truly,
Herman Small

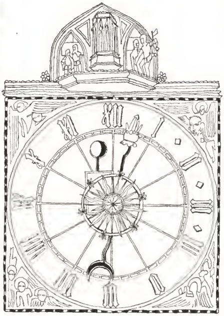
Dear Mr. Small:

You sound like the sort of person who is going to be taking charge of things in the comparatively near future and we had better not kid around with you.

As a matter of fact we have been working hard for years on film for direct electron recording of cathode-ray images. We have even sold a little of it, but not much. It seems to be a very good way to pack information at megacycle frequencies into far more compact form than magnetic recording permits. (We assume you are familiar with megacycles.) Sale is still small because there is as yet very little equipment around that can make use of such film. To the extent that this development is involved in the planning of the financial program that you intend to launch in 1975, we wish you luck. It may be big then or it may have died. If we knew, we'd be bolder now.

On films for use in the laser art, it is the same old question of how bold to be with funds such as you yourself might have already entrusted to us (if it had not been for the matter of consent). It seems fairly clear that by the time you settle down into the driver's seat, much more of what we have already learned in making the film that has kept you interested in personal photography will have moved from that area into the use of color film technology in dealing with modulated optical frequencies. We have the color film technology in pretty good shape, but we can't afford to bet it on every horse in the race. It costs an awful lot of money to make a few feet of new color film not made before, even if you have a pretty good idea of how to make it. Lots of ideas will doubtless be brought to us in hope of film. We too need a little luck in picking winners.

Very truly yours,
EASTMAN KODAK COMPANY



SCIENCE AN

One-Upmanship

Within the past two months the U.S. and the U.S.S.R. have revealed that they have taken three more steps toward a nuclear holocaust. Almost seeming to respond to the earlier announcement that the U.S. would proceed with a "light" antimissile defense, Russian sources spoke of a new offensive missile delivery system. U.S. sources thereupon described first a new type of antimissile warhead and then a new multi-city missile system.

The Russian weapon is an orbital bombing system. A nuclear warhead is fired into a low orbit around the earth. At some point—presumably before the first orbit is complete—a retrorocket slows the warhead, which thereupon follows a ballistic trajectory to its target. This "Fractional Orbital Bombardment System" (FOBS) had been foreshadowed by Russian statements as long ago as 1965 and by Russian rocket tests that involved low orbits and early reentry. Secretary of Defense Robert S. McNamara pointed out that the FOBS trajectory would avoid detection by the U.S. early-warning radar system and would make it impossible to determine the intended target until the "deboosting" rocket fires about three minutes before impact. On the other hand, he said, accuracy and payload size are substantially decreased in the FOBS compared with conventional missiles, and the U.S. had decided some time ago not to develop such a system.

The first U.S. development is an antimissile warhead that emits a broad spectrum of X rays calculated to destroy incoming missiles outside the atmosphere. Thermonuclear weapons emit large amounts of X radiation, and in the vacuum of space X rays can travel virtually without hindrance. If enough of the radiation is absorbed by the casing or internal workings of an offensive warhead, its electromagnetic energy is converted into heat that can destroy the warhead. The hitch has been that X rays of different wavelengths are optimally absorbed by different materials; knowing the characteristic emissions of a thermonuclear explosion, one could supply a shield that would soak up the radiation and protect the warhead proper. The claim is that the proposed "spectrum bomb" will emit X rays across a band of frequencies, so that no feasible shield would be able to absorb them all.

The second U.S. development, nicknamed a "space bus," is a single vehicle that can drop off a number of warheads one after the other, each aimed at a different enemy city. Such a vehicle represents a step beyond the multiple-warhead missiles discussed in the past, which would have delivered several thermonuclear weapons in one general area.

The spectrum bomb lends credibility to the U.S. decision to establish a light antimissile defense. The Russian advance provides a new argument for proponents of a "new generation" of U.S. offensive weapons, and the multi-city missile promises to be one such new weapon. In *The New York Times Magazine* former Deputy Secretary of Defense Roswell L. Gilpatric called attention to the "inexorable rhythm" of measures and countermeasures in the arms race. In view of this country's clear present nuclear superiority any initiative to slow the race will probably have to come from the U.S., he said, and this is unlikely in an election year.

Ecological Warfare

Defoliation and crop destruction by U.S. forces in Vietnam may cause civilian casualties and result in long-term agricultural and ecological damage, according to Arthur W. Galston of Yale University. His article on herbicides is part of a special issue on chemical and biological warfare of *Scientist and Citizen,* the journal of the Scientists' Institute for Public Information. Galston's

major concern is that widespread spraying of herbicides "can affect the land, water and living things" that support a population. Little is known even of the direct effects of herbicides on specific plants, and far less of the complex and interrelated effects on the ecological chains in which the affected plants are links.

Galston reports that some 1.5 million acres of land may have been sprayed during 1967, including perhaps 5 percent of South Vietnam's cultivated acreage. The primary weapons are two hormonal preparations, 2,4-D and 2,4,5-T, and cacodylic acid, an arsenic compound. Aerosols of the first two substances, which are applied extensively as jungle defoliants, have often drifted and caused inadvertent damage to food crops. The cacodylic acid is more dangerous to man: it is persistent, arsenic toxicity is cumulative and arsenic may be concentrated in plants. Any herbicide, moreover, can have unforeseen effects on the biosphere by affecting a food chain. For example, derivatives of certain herbicides could kill microorganisms on which marine life—an important element in the Vietnamese diet—feeds.

As for the direct effects of crop destruction (with herbicides or by contaminating or dispersing harvested grain), Jean Mayer of the Harvard School of Public Health points out that in any wartime famine situation a major effort is made to keep the armed forces decently nourished. Crop destruction is therefore unlikely to affect the Vietcong militarily. It is a weapon "whose target is the weakest element of the civilian population": children, the elderly, and pregnant and lactating women.

Milton Leitenberg, a biochemist on the *Scientist and Citizen* staff, considers a different form of biological warfare: the delivery of disease-producing organisms such as bacteria and viruses. He reviews the U.S. military research program in this area and in particular the implications of new discoveries concerning the transfer of multiple drug resistance from one strain of bacteria to another (see "Infectious Drug Resistance," by Tsutomu Watanabe; SCIENTIFIC AMERICAN, December, 1967). Leitenberg states that workers at the U.S. Army Chemical Corps' center at Fort Detrick in Maryland have succeeded in

transferring extrachromosomal resistance factors into a number of militarily significant bacterial strains.

Third Second

How long is a second? Putting aside poetical and other subjective assessments, this fundamental unit of time is now defined in terms of induced atomic oscillation as "the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two hyperfine levels of the fundamental state of an atom of cesium 133." The definition was adopted in October at the 13th meeting of the General Conference on Weights and Measures to convene since uniform international standards of measurement were first established in 1875.

As a matter of convention, time is measured in terms of the daily rotation of the earth. Thus the first scientifically defined second was declared to be one 86,400th of a mean solar day. The earth's rotation soon proved too erratic to serve as a useful standard; since the year 1900, for example, cumulative error on the order of about one part per 100 million has made the time told by counting the earth's rotations lag 30 seconds behind the time told by counting its annual revolutions around the sun. Plagued for decades by this inconsistency, the International Committee on Weights and Measures in 1956 revised the formal definition of a second from a sizable fraction of a solar day to a very small fraction (1/31,556,925.9747) of the tropical year.

The 1956 second, known as the ephemeris second, is accurate within a few parts per billion, but because it is based on astronomical observations averaged over several years it is not easy to use for the measurement of unknown time intervals by direct comparison. Because the duration of the third, or atomic, second is measured in units of frequency, it can readily be compared with laboratory oscillators, and the precision of such comparisons is better than one part per 10 billion. Indeed, a pair of cesium resonators built in separate laboratories will agree to within a few parts per 100 billion—equivalent to a cumulative error of only one second per 3,000 years.

Yes, No, Don't Want to Know

A strong caution against attaching too much weight to polls of public opinion, particularly concerning political issues, has been expressed by Leo Bogart, president of the American Association for Public Opinion Research. His presidential address to the group is published in *Public Opinion Quarterly*. Bogart suggests that many of the people approached by pollers really have no opinion on the issue in question and indeed often do not want to have one. " 'Don't know' in response to a survey question," he writes, "often means 'Don't want to know,' which is another way of saying, 'I don't want to get involved.' " In many such cases the attitude reflects the respondent's feeling that the issue is no responsibility of his.

Even when a respondent does give an opinion, Bogart continues, it is quite likely to have been formed on the spot and to be based on limited or erroneous knowledge of the factors involved in the issue. The question then arises, he says, of how sensitive a public official should be to polls, knowing that they reflect many hastily formed and readily changeable opinions that in numerous cases are based on fragmentary knowledge. Bogart's answer is that "if, as is often the case, a substantial percentage of the public is uninformed about and uninterested in a subject, then actions contrary to the apparent will of the polled majority may nonetheless fall within the latitude that a compliant body politic permits its leaders."

Bogart sees a valuable role for surveys in ascertaining the extent of public ignorance on matters of fact. "We measure public opinion for and against various causes, with the 'undecided' as the residue," he says. "Often what we should be doing instead is measuring the degrees of apathy, indecision or conflict on the part of the great majority, with the opinionated as the residual left over."

Holography by Sound

For the past 18 months or so workers at a number of research laboratories have been trying—with varying degrees of success—to extend the optical technique of holography, or photography by wave-front reconstruction, to the realm of sound waves. The results of one such investigation are reported in a recent article in *The Journal of the Acoustical Society of America* by Alexander F. Metherell, Hussein M. A. El-Sum, John J. Dreher and Lewis Larmore of the Advanced Research Laboratories of the Douglas Aircraft Co.

In the experiments performed by Metherell and his colleagues the object to be "photographed" was placed between a high-frequency sound source and a scanning microphone, which was moved in a plane at right angles to the object and the sound source. The sound energy picked up by the scanning microphone was converted to light energy by connecting the microphone to a cathode-ray tube. The hologram, or interference pattern, produced on the tube by the disturbed sound wave from the object was then photographed. When the resulting photographic transparency was "developed" by shining coherent laser light through it, a three-dimensional image of the object was produced.

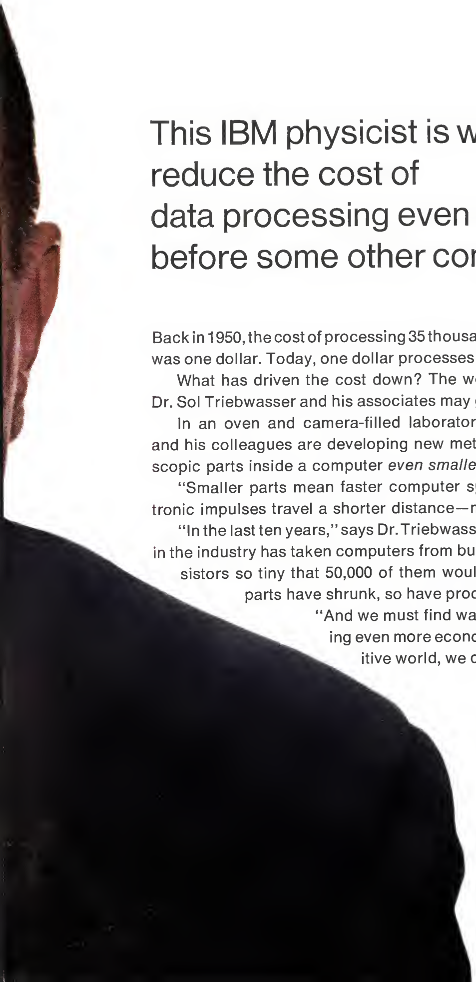
Although such acoustical holograms taken in air do not show as much detail as optical holograms, the acoustical technique may be more useful in special situations—such as under water, where sound waves can penetrate much farther than light waves. According to Metherell and his colleagues, the advantages of acoustical holography over other acoustical image-formation techniques (such as sonar) are "simplicity, the reconstruction of the image in three-dimensional form, the enormous depth of field, the insensitivity to the turbulence and turbidity of the medium, and the capability of retrieving the information about the target from discrete sampling points."

Other possible applications of acoustical holography include medical diagnosis (instead of X rays), geological prospecting and nondestructive testing. The Douglas group has also outlined a method for making acoustical holograms in color.

Interlocked DNA

It has been known for some time that the genetic material deoxyribonucleic acid (DNA) occurs not only in the nucleus of the cell but also, in small amounts, in the extranuclear bodies called mitochondria, which provide animal and plant cells with most of their energy. Although the function of the mitochondrial DNA is unknown, it presumably has the same role as nuclear DNA: to provide instructions for the synthesis of protein. Normally the DNA extracted from mitochondria is in the form of a ring. It has now been discovered by Jerome R. Vinograd and his associates at the California Institute of Technology that molecules of DNA from mitochondria sometimes form chains consisting of two or more interlocking rings.

These catenate, or chainlike, forms of DNA have been isolated from the mitochondria of several species, but the best-studied examples have been obtained from two kinds of human cell, both associated with cancer. The first chains were obtained from a widely cultivated laboratory strain of human cells known as HeLa cells. Subsequently



similar chains were found in white blood cells obtained from three patients with leukemia.

In an article in *Nature* describing these unusual structures, Vinograd and David A. Clayton propose that the interlocking rings are produced when the DNA molecule is being replicated, or perhaps during recombination, a process in which two molecules of DNA exchange parts. Vinograd and Clayton visualize several simple schemes in which two rings of DNA could become intertwined as a result of breaking and recombining. The interlocked structures show up clearly in electron micrographs. Although structures containing two interlocked rings have been found in the mitochondria of normal human subjects, the investigation to date suggests that the DNA catenates, particularly those with several rings, are more frequent in the leukemic patients.

Cells of Mice and Men

The first hybridization of normal human cells with those of another animal has been demonstrated by Mary C. Weiss and Howard Green of the New York University School of Medicine. The hybrid cells developed spontaneously when human fibroblast cells were grown together with mouse fibroblast cells in a special culture medium. Limited success had been achieved earlier in hybridizing the cells of man and mouse by using cultures of cancer cells and employing a virus to fuse the two species of cell together. These fused hybrids underwent only a few cell divisions and thus did not yield established lines of hybrid cells.

The N.Y.U. workers report in *Proceedings of the National Academy of Sciences* that their hybrid colonies of man-mouse cells grew successfully through more than 100 generations over a period of four to six months. All or nearly all the mouse chromosomes (51) were duplicated in the hybrid cells generation after generation, but the number of human chromosomes (normally 46) dropped after several generations to between three and 12. From the viewpoint of the investigator this is an advantage because it reduces the complexity of the biochemical reactions that are potentially traceable to the human genes. Thus in the N.Y.U. experiment the original human cells had the ability to synthesize the enzyme known as thymidine kinase, whereas the mouse cells lacked that ability. Since the hybrid cells grew successfully in a culture that required thymidine kinase, the N.Y.U. workers concluded that the human gene (or genes) responsible for making thymidine kinase must be located in a small number of human chromosomes present in the hybrids. By the same token, the hybrid cells resisted infection by poliomyelitis virus, indicating that the virus was unable to penetrate the cell membrane, because of either a lack of essential human-cell elements or interference by mouse cell elements.

Altitude and Athletics

Athletes planning to compete in the Olympics in Mexico City this year may need months of acclimatization to the thin air of the city if they hope to be at their best for the games. The possibility is indicated by findings involving six middle-distance runners who underwent four weeks of tests at sea level in England followed by four weeks of similar tests in Mexico City, where the altitude is 7,450 feet. The work is reported in the *Journal of Physiology* by L. G. C. E. Pugh of the National Institute for Medical Research in London.

The tests included time trials at distances of a mile and three miles and five-minute periods of heavy exercise on an ergometer, an apparatus on which the men pedaled while various physiological measurements were made. During the first week of tests in Mexico City the men were 8.5 percent slower on the three-mile run than they had been in England and 3.6 percent slower on the one-mile run. At the end of the four weeks in Mexico City the differences were 5.7 percent and 1.5 percent respectively. On the ergometer the maximum intake of oxygen was 14.6 percent lower on the second day in Mexico City than it had been in England; on the 27th day the difference was 9.5 percent.

Pugh found that the reduced density of the air in Mexico City conferred one benefit: the resistance it presented to the runners was less than they had to overcome at sea level, and so they were able to counteract slightly the otherwise adverse effect of the reduced oxygen content of the air on their running times. Nonetheless, Pugh said, "an athlete's chances of success in international games at an altitude of 2,270 meters would depend to an important degree on . . . the time allowed for acclimatization; what the end point in acclimatization would be, and how long it would take to reach it, are matters for further investigation, but the present results are in line with the accepted physiological view that the time required for full acclimatization is a matter of months rather than weeks."

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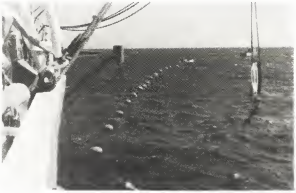

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Remote Sensing of Natural Resources

Several devices are now available to supplement the aerial camera in detecting natural resources from airplanes and spacecraft. They include radar, gamma ray detectors and sensors of infrared energy

by Robert N. Colwell

As pressures on natural resources increase, because of growing populations and rising standards of living, it becomes steadily more important to manage the available resources effectively. The task requires that accurate inventories of resources be periodically taken. Until as recently as a generation ago such inventories were made almost entirely on the ground. Geologists traveled widely in exploring for minerals; foresters and agronomists examined trees and crops at close hand in order to assess their condition; surveyors walked the countryside in the course of preparing the necessary maps. The advent of aerial photography represented a big step forward. Within the past few years the making of aerial photographs has been augmented by a new technique, in which sensing is done simultaneously in several bands of the electromagnetic spectrum. The name often given the technique is remote sensing. In its fullest form the technique ranges through the spectrum from the very short wavelengths at which gamma rays are emitted to the comparatively long wavelengths at which radar operates. In this way one can secure far more information about an area than can be obtained with conventional photography, which is limited to the visible-light portion of the spectrum.

Remote sensing can be done from aircraft or spacecraft, including unmanned satellites. It employs cameras and a number of other sensing devices. To some extent the data obtained by the sensing devices can be processed and interpreted automatically, so that a large volume of information can be dealt with rapidly.

The information thus obtained is useful to investigators in many disciplines. Geologists use remote sensing to find deposits of minerals and petroleum, to improve their understanding of the distribution and origin of major geological features and to study the exchanges of energy associated with such crustal disturbances as earthquakes and volcanic eruptions. Soil scientists can take inventory of the important physical and chemical characteristics of soils by relating these characteristics to the geological features and the types of vegetation found on images obtained by remote sensing. Foresters and agriculturists can determine what kinds of trees and plants are growing in an area, can assess the health of the forest or crop and can estimate harvests. Similar information can be obtained by workers interested in populations of livestock, wildlife and fish.

By means of remote sensing hydrologists can locate useful aquifers and can estimate the volume of surface and subsurface flow in watersheds. Oceanographers can map the movements of ocean currents, marine organisms and water pollutants. They can study in detail the daily and seasonal changes in tides, shorelines and the state of the sea. Geographers can analyze land-use patterns over broad areas and can study the interplay of climate, topography, plant life, animal life and human activity in a particular area. Engineers planning large construction projects such as highways, airports and dams can obtain data on landforms, rock materials, soils, types of vegetation and conditions of drainage. It goes almost without saying that remote sensing in various parts of the spectrum is invaluable to map makers in their efforts to identify ground features and to position them accurately.

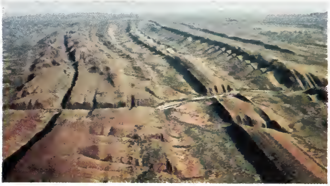
The earliest aerial photographs, made somewhat more than a century ago, suffered from the deficiencies of the cameras and emulsions and from the necessity of using such unsteady vehicles as balloons and kites for platforms. Today the array of equipment available for remote sensing can be matched to almost any requirement. Whatever the platform—helicopter, airplane or satellite—the camera can be mounted so that it is stabilized against roll, pitch and yaw and insulated against vibration. The aberrations of the lenses in cameras have been greatly reduced so that sharp images can usually be obtained. Roll film of high dimensional stability has almost entirely replaced emulsion-coated glass plates. Several kinds of color film are available to augment or replace black-and-white film in both the visible and the infrared portion of the spectrum.

Remote-sensing Equipment

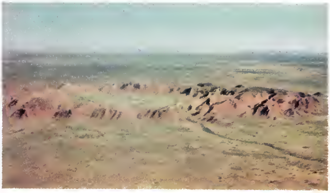
Among the many types of equipment developed for remote sensing, six show the most value or promise for the inventory of natural resources. They are the conventional aerial camera, the panoramic camera, the multiband camera, the optical-mechanical scanner, side-looking airborne radar and the gamma ray spectrometer.

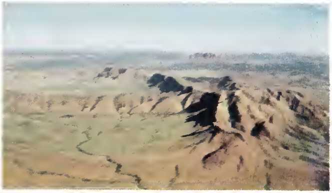
A conventional aerial camera has four basic components: a magazine, a drive mechanism, a cone and a lens [*see top illustration on page 58*]. The magazine

CENTRAL AUSTRALIA'S characteristic topography appears in the photograph on the opposite page, made from the *Gemini V* spacecraft on August 27, 1965. The spacecraft was at an altitude of 165 miles; the area shown is west of Alice Springs. An experienced interpreter can use such a photograph to obtain information about a variety of natural resources and land uses. Some ways the photograph can be interpreted are illustrated on pages 56 and 57.

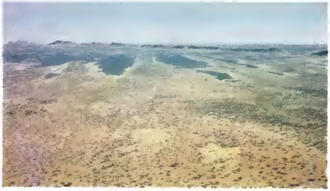


MAIN FEATURES of the *Gemini* photograph (*see key on opposite page*) include two geological formations indicative of sedimentary rocks. *A*, at left, shows steeply dipping beds in the MacDonnell Range; *B*, at right, shows eroded rocks in the Waterhouse Range.

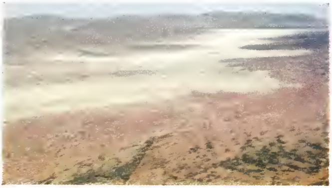




FURTHER INTERPRETATION of the *Gemini* photograph led to the conclusion that *C*, known as Gosse's Bluff, is a meteorite crater (*left*). The region marked *D* on the spacecraft photograph and shown at right above has several features that indicate alluvial soil.



SOIL RESOURCES ascertained from study of the *Gemini* photograph include *E*, shown in a low-angle view at left; dunelike patterns suggest a sandy soil. *F*, at right, is a dry lake bed; there the interpreter would predict the existence of heavy clay soils.



VEGETATION BOUNDARIES appear more distinctly in the *Gemini* photograph than in low-angle views. *G*, at left, is a boundary between mulga, a type of acacia tree, and spinifex, a grass. *H*, at right, is a boundary between Mitchell grass (*yellow*) and spinifex.

is the light-tight box that holds the film. Usually it can be detached from the rest of the camera. The film is ordinarily in the form of a continuous roll 9½ inches wide and 200 feet long. Such a roll will accommodate about 250 exposures, each nine inches square.

The drive mechanism is a series of cams, gears and shafts designed to move the film from the supply spool to the take-up spool. As the film moves, rollers guide it over the front surface of a locating plate. One of the rollers is designed to meter the amount of film passing from the supply spool to the take-up spool between exposures, thereby providing a correct and uniform spacing of exposures on the roll of film.

During an exposure, suction is created behind the locating plate by means of a venturi tube or a special vacuum-cylinder-and-piston apparatus built into the magazine. The suction, transmitted to the film through small perforations and grooves in the locating plate, holds the film in a flat plane against the locating plate at the instant of exposure. In this way distortions that would be caused by wrinkles in the film at the moment of exposure are minimized.

The cone is a light-tight unit that holds the lens in the correct relation to the film. The length of the cone is governed by the focal length of the lens, which is essentially the distance from the center of the lens to the film. It is not unusual for a magazine to have interchangeable cones to accommodate lenses of differing focal lengths. Most of the aerial photography done for the inventory of natural resources uses focal lengths of six, 8¼ or 12 inches.

The lens is a compound one that is carefully designed to cast an undistorted image on the large area of the film. Aerial cameras usually have fixed-focus lenses with the focus at infinity; the camera is used so far above the ground that such a focus will provide a sharp image of all objects on the ground. In most aerial cameras the shutter is between the front and the rear elements of the lens. The drive mechanism of the camera recocks the shutter automatically after an exposure.

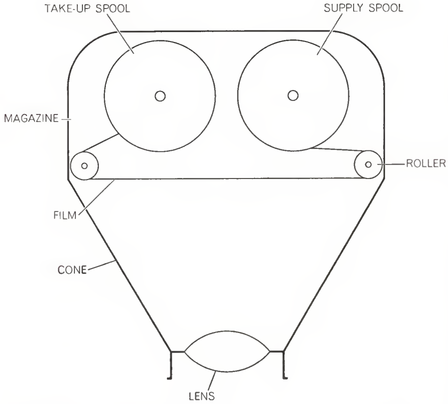
The panoramic camera [*see bottom illustration on next page*] makes it possible to photograph a large area in a single exposure at very high resolution, meaning with a high degree of sharpness of image in every part of the photograph. The camera meets a need but creates some special problems. In order to get a sharp image when photographing large areas, one paradoxically needs a narrow angular field so as to minimize aberrations of the lens. Such a field is provided in the panoramic camera by a narrow slit in an opaque partition near the focal plane of the camera. The slit is parallel to the camera platform's line of flight. With such a slit, however, one will be able to photograph only a narrow swath of terrain unless the optical train of the camera is equipped to pan, or move from side to side, as the aircraft advances. The optical train of the panoramic camera is designed to make such movements.

On the other hand, for the panoramic camera to maintain a uniformly clear focus as the optical train moves, the frame of film being exposed must be held in the form of an arc instead of being kept flat as in a conventional camera. With the film in an arc the photographic scale becomes progressively smaller as the distance of objects on the ground increases to the left and right of the flight path. In some applications the scale problems outweigh the advantage of a panoramic field of view, so that it is preferable to use a conventional camera.

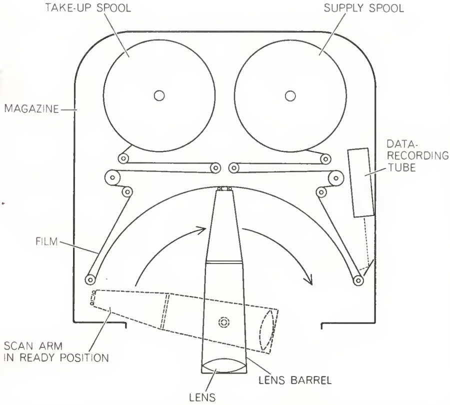
Related Devices

The multiband camera makes photographs simultaneously in several bands of the spectrum. In essence it provides a variety of lens, filter and film combinations, each designed to obtain maximum information from a particular band. A typical camera might have nine such combinations [*see illustrations on page 59*]. Together the lenses give the camera a capacity to sense in the range of

PRINCIPAL FEATURES of the *Gemini* photograph on page 55 are identified. The arrows show direction in which the low-angle aerial photographs on the opposite page were made.



CONVENTIONAL AERIAL CAMERA uses film in roll form and can make about 250 exposures, each nine inches square. Magazine holds the film. Cone positions lens with respect to the film, at a distance governed by the focal length of the lens. Film being exposed is held flat against a locating plate to minimize distortions and provide uniformly sharp images.



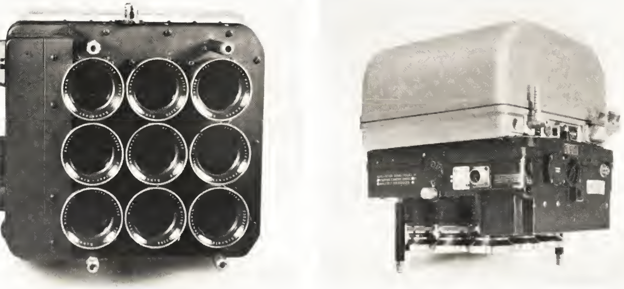
PANORAMIC CAMERA was developed to provide sharp aerial photographs of large scale. Since the camera must have a long focal length it must also have a narrow angular field. As a result it requires a scanning mechanism that moves the lens barrel to left and right. At any instant during the course of a scan only light passing through a narrow slit falls on the film.

wavelengths from .4 to .9 micron, which is to say throughout the visible spectrum and into the very near infrared. All nine shutters click simultaneously, thus yielding nine photographs, each with tonal values that are distinctive for its portion of the spectrum. Study of distinctive tonal values in nine photographs of an area enables the interpreter to determine a "tone signature" for each type of object. As a result he obtains much more information about the area's natural resources than he could obtain from any one of the photographs.

The optical-mechanical scanner meets the need for a device that will sense farther in the infrared–in what is commonly called the thermal infrared region. Ordinary photographic film is not sensitive to wavelengths in the thermal infrared region. It would be possible to coat a film with a material sensitive to such wavelengths, but then the problem would arise of protecting the film from the thermal energy being emitted by the camera. Just as the conventional camera must be a light-tight box to keep light-sensitive film from fogging, so a thermal infrared camera would have to have a heat-tight box to keep heat-sensitive film from fogging. In fact, the box would have to be continuously cooled almost to absolute zero, which is a practical impossibility for a large airborne sensing device.

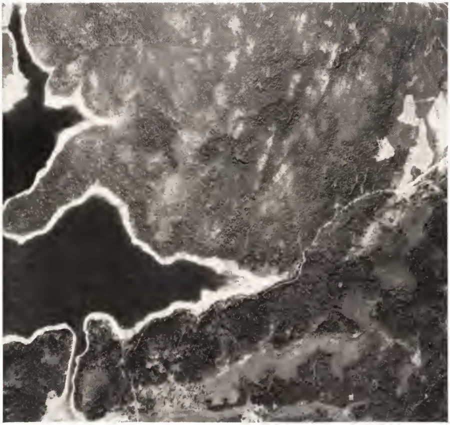
Thus a "camera" that translates thermal energy directly onto film is out of the question. It is possible, however, to obtain photographic images of thermal energy indirectly, and that is what the optical-mechanical scanner does. The device uses a detector that consists of a coating of some infrared-sensitive material such as copper-doped or gold-doped germanium on the end of an electrical conductor. The material occupies an area no bigger than a pinhead. It is entirely feasible, even in an airborne system, to cool this small detector with liquid nitrogen for sensing at wavelengths of from three to six microns and with liquid helium for longer wavelengths.

A rotating mirror directs to the detector energy emanating from the terrain. At any instant the mirror views only a small segment of terrain. Infrared photons striking the detector generate an electrical signal that varies in intensity according to the amount of thermal energy coming from the part of the terrain then being viewed by the mirror. The signal, by being converted to a beam of electrons, can generate visible light, such as the moving luminous spot on the face of a cathode-ray tube. The spot grows brighter or dimmer in direct



MULTIBAND CAMERA has nine lenses and nine film-filter combinations, each designed to function best in one part of the spectrum. Camera permits more positive identifications to be made of certain natural resources from their multiband "tone signatures."

MULTIBAND EXPOSURE was made with a multiband camera. The wavelengths of energy represented range from .38 micron (*top left*) to .9 micron (*bottom right*), which covers not only the visible spectrum but also parts of the ultraviolet and near-infrared regions.



PANCHROMATIC VIEW of the Bucks Lake area of the Sierra Nevada was obtained with panchromatic film, meaning film that is sensitive to the entire visible spectrum. Such a photograph is particularly useful for estimating the density of vegetation and for identifying certain species of vegetation. The area is part of the one shown in color on page 63.

RADAR VIEW of the same area is especially useful for discerning types of vegetation that appear less clearly in panchromatic view. Radar also shows drainage networks more clearly.

proportion to the strength of the electron beam. An image of the light is recorded on photographic film, and the analyst obtains what is in effect a thermal map of the ground.

The scanner is not limited to sensing in the thermal infrared region of the spectrum. It can provide multiband imagery in any band from the near ultraviolet through the visible and photographic infrared regions and into the thermal infrared. Moreover, in "photographs" made by the instrument the general shape of ground features is essentially the same in every band, so that the images can be superposed or otherwise compared readily.

Side-looking airborne radar, commonly called SLAR, brings to remote sensing such valuable attributes as all-weather and around-the-clock usefulness and the ability to penetrate a cover of vegetation. Because radar operates at much longer wavelengths than the other equipment I have described, however, it does present difficulties in obtaining high resolution. Recent developments such as SLAR equipped with a synthetic aperture system have brought about large improvements in the quality of radar imagery.

In the SLAR system a transmitting antenna in the airplane sends a short pulse of microwave energy out one side of the plane. The energy strikes a roughly circular area on the ground, and a receiving antenna collects the energy reflected back to the plane. The greater the distance from the aircraft to any portion of the target, the greater the time delay in the return of the reflected signal. By accurately measuring the time delay, SLAR differentiates the echoes that return to it from various small concentric rings. Each ring represents the locus of all points within the large circle that are roughly equidistant from the plane.

Within any ring there is a spot just opposite the aircraft that moves along at the same speed as the aircraft. At any given time the distance from the aircraft to all other points on the ring is either increasing or decreasing. Here the Doppler effect comes into play: the frequency of the reflected signal changes according to whether the plane is approaching a given point or receding from it. As a result the microwave energy reflected back to the aircraft from such points differs in frequency from the energy transmitted to them. The radar receiver is designed to accept energy of approximately the same frequency as the initial pulse and to reject significantly different frequencies.

Because of the two discriminating effects—one depending on time delay and

the other on the Doppler effect—the radar receiver accepts at any given instant only the energy that meets two conditions: that it be from the narrow ring within which the time delay is such that the energy is at that instant striking the receiving antenna, and that it be in the particular part of the ring that is directly opposite the aircraft—the part having almost no relative velocity with respect to the aircraft and thus exhibiting no Doppler effect. Together the two discriminating features provide the synthetic aperture. The technique greatly improves the spatial resolution of the system.

Radar images are transformed into photographic images in the same way that photographic images are produced by the optical-mechanical scanner. The microwave energy is converted to an electron beam that operates a cathode-ray tube, and the light is recorded on film. The density on each portion of exposed film is in proportion to the brightness of the radar signal coming from the corresponding spot on the terrain.

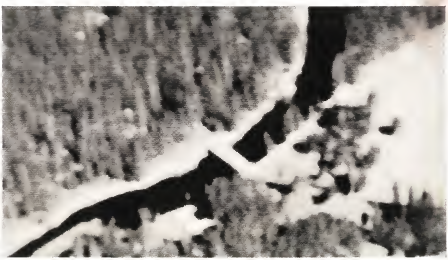
The gamma ray spectrometer functions at very short wavelengths—a millionth of a micron or less, compared with the billion microns or more at which radar and other microwave sensors operate. The spectrometer is excellent for locating radioactive substances, even when it is operated at altitudes of several thousand feet above the ground. It is therefore useful in prospecting for minerals. Moreover, a gamma ray spectrometer can be designed to operate in as many as 400 different channels, or wavelength bands, so that the instrument has considerable ability to differentiate each of several radioactive minerals.

Analysis of Data

Remote sensing of natural resources rests on the fact that every feature of the terrain emits or reflects electromagnetic energy at specific and distinctive wavelengths. The analyst cannot hope to accomplish much in the way of interpreting the data, however, until he takes the time to determine what spectral response pattern—what multiband tone signature—to expect from a given feature. The best means of accomplishing this is to set up a test site in which each type of feature that is to be identified by remote sensing is exhibited. By studying multiband images obtained from the test site the analyst will equip himself to recognize, by their unique spectral response patterns, the features that are of interest to him in a sensing mission. Ideally at least one such test site should be includ-

THERMAL INFRARED image of a site in Yosemite Valley shows several campfires better than sensing in other bands would. Thermograph, which senses infrared wavelengths and uses them to govern a source of visible light that is recorded on film, was about a mile above the valley. Smallest fire detected was one charcoal briquette less than a cubic inch in size.

ADDITIONAL VIEW of the Yosemite Valley site from the same station was made with the thermograph set to function at wavelengths of eight to 14 microns and so brought out vegetation in meadows (*right*). The fire-sensing thermograph functioned at three to five microns.



TIMBER RESOURCES stand out in this thermal infrared view of same site. Thermograph was set for eight to 14 microns but the image was obtained by day rather than by night.

MANGROVE TREES in a swamp near Brisbane, Australia, appear normal in this panchromatic aerial photograph. Sensing in another part of the spectrum told a different story.

INFRARED VIEW of the same mangroves shows that the trees at upper left have been damaged. Mud had been pumped into the basin. Unhealthy trees and crops have a dark tone in infrared because of a previsual loss in reflectance at infrared wavelengths of .7 to .9 micron.

ed in each sensing flight for calibration purposes.

Eventually it may become possible to identify every feature in a given area. The technique of sensing in a variety of wavelengths promises to speed progress toward that objective. As the number of spectral bands used in remote sensing is increased, the identifying response pattern for each natural resource becomes more complete and more reliable.

At the same time the increase in spectral bands sensed means that the task of analyzing data grows larger. It can become unmanageable unless the analyst has equipment that helps him to correlate the multiband images. The problem is that he confronts several black-and-white images, each with distinctive tone values for particular features. He can find himself in confusion if he interprets one image, goes on to another, refers back to the first and so on for a number of images.

One way to deal with the problem is to reconstitute the various multispectral black-and-white images into a single, composite color image. The usual technique is to project each black-and-white image through a colored filter. A battery of projectors is used so that all the images can be superposed simultaneously on the screen.

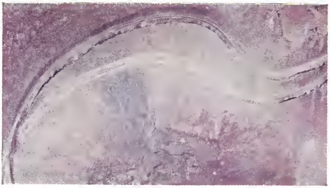
In such a composite image the tone or brightness of a ground feature as recorded in any given spectral band is used to govern the intensity of one of the colors used in the composite. By varying the selection of colored filters the analyst can change the color contrast of the composite. Often by this means he finds that one combination of filters provides the best interpretability of one kind of feature, whereas other filters provide better interpretability of other features. The bottom two illustrations on page 64 are composites made in this way.

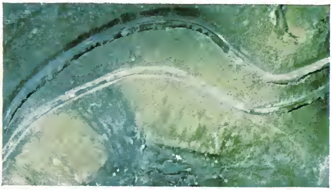
A second way of correlating multiband images is to use a battery of photoelectric sensors to scan all the black-and-white images simultaneously. The sensors record degrees of brightness. For each spot scanned the sensors automatically determine a tone signature, which in theory will be identifiable with some signature established from the test site. By this means the analyst can identify what features the remote-sensing equipment detected on the ground.

In its ultimate form the technique will result in a tape printout indicating the objects and conditions encountered at every spot in the multiband imagery. The method has not been developed to that stage, but even at its present stage of development it is able to provide

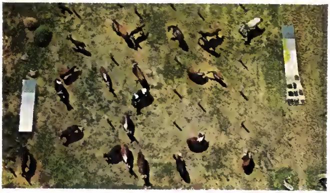
WILD-LAND RESOURCES are studied in a test area in the Bucks Lake region of the Sierra Nevada. This photograph was made from a camera station on a rock 2,000 feet above the lake. The station is used to make simulated aerial photographs of a known area. Such terrestrial photographs can be used as guides in interpreting similar photographs, obtained from aircraft or spacecraft, of regions where the wild-land resources need to be identified. A normal color photograph is only one of several types of photograph used for evaluating resources. Sensings can also be made in other wavelength bands of the spectrum to detect different physical features.

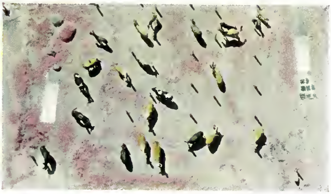
SAME AREA of the Sierra Nevada is photographed in infrared. The film used to make both this photograph and the one on the cover of this issue contains a red dye that is sensitive to near-infrared wavelengths of .7 to .9 micron. The false colors often provide more scope for interpretation than is possible with other film. Largest amounts of infrared energy produce the reddest color.



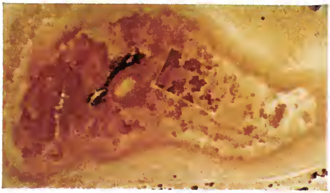


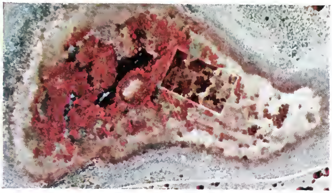
ROCK TYPES are differentiated more clearly in an infrared photograph (*right*) than in a full-color photograph (*left*) of the same area. The technique may aid in identifying rocks on moon that contain hydrated salts and could be a source of water for astronauts.



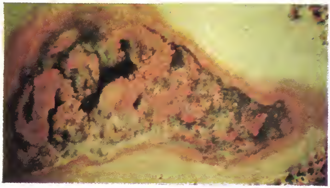


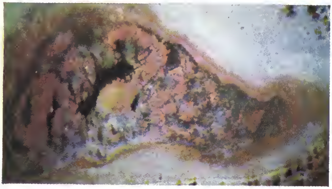
LIVESTOCK can often be identified more precisely in an infrared photograph than in normal color. Here the same group of livestock is photographed in normal color (*left*) and in infrared (*right*). Test panels appear at the left and right sides of the photograph.





RANGELANDS merit study in both normal color and infrared photography. Two types of forage, bitterbrush and big sage, appear more clearly in infrared photograph at right than in the normal-color photograph at left. Bitterbrush is bright red; sage, dark.





SAME AREA of rangeland is shown in a multiband technique. Black-and-white pictures, exposed at various wavelength bands, are projected separately with filters of different colors; the projections are combined in single images that bring out significant features.

enough automatic analysis of images to reduce considerably the amount of work done by the analyst. The illustrations at right show the results of photoelectric scanning of an aerial photograph.

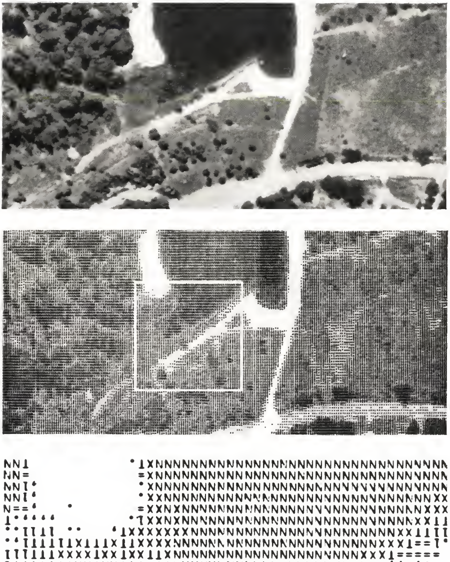
In a third technique the multiband sensing system records on magnetic tape, rather than on photographic film, the signal strength from each object in each spectral band. Thereafter the procedure is essentially the same as it is in the photoelectric scanning technique. The third method provides a complete inventory only moments after the remote sensors have been flown over the areas of interest. It also makes possible an analysis of the signal strengths emanating directly from the sensed objects, whereas in the second method the analysis is of signals that may have been degraded in the process of forming multiband images of the objects.

Some Applications

Against the background of sensing equipment and analytical techniques that I have described it is possible to consider in more detail some of the ways in which remote sensing can contribute to the management of natural resources. Several of the possibilities are illustrated in the photograph on page 55, which was made from the spacecraft *Gemini V* and shows a large area of central Australia. The principal features of the area are identified by letters in the black-and-white reproduction of the photograph on page 57.

The southern part of the MacDonnell Range [*A in the photograph on page* 57] has steeply dipping parallel beds that the geologist would recognize as indicating the presence of folded sedimentary rocks varying in hardness and in susceptibility to erosion. The characteristics of the northern part of the range would suggest to the geologist that the rocks there are igneous or metamorphic. Evidence of faulting appears in the linear ridge that runs through the northern part of the range. The characteristics of the Waterhouse Range [*B in the illustration*] suggest sedimentary rocks that long ago were folded into an anticline, or upfolded structure, and have since been eroded to varying degrees. Careful study of shadow detail in the vicinity of the circular structure known as Gosse's Bluff [*C*] reveals that it is a hollow outcropping of rocks that probably resulted from the impact of a large meteorite.

From even this crude interpretation of the photograph a mineralogical prospector would be able to deduce that some of the best prospects for metallic



AUTOMATIC ANALYSIS of tonal qualities can be done with a photoelectric scanner. At top is a photograph made with a multiband camera. At center is a scanner's print in which "N" shows darkest tones and other symbols represent lighter tones. At bottom is an enlargement of the outlined area. Since each natural resource tends to have a unique multiband tone signature, automatic encoding of tones may lead to automatic resource inventories.

minerals are to be found along the discernible fault lines in the MacDonnell Range. The petroleum geologist would be interested in the folded anticline of the Waterhouse Range. It is equally significant that the searchers for both metals and petroleum often can eliminate nearly 90 percent of the vast area shown in a small-scale photograph as being unworthy of detailed mineralogical or petroleum surveys. Important deposits of either kind are rarely found in areas that photographically show little geologic evidence of their presence.

The *Gemini* photograph is also helpful in assessing the soil resources of the area. For example, it can be assumed that most of the central region [*D*] has deep alluvial soils because there are nearby mountain ranges from which alluvial deposits are likely to have come, because the pattern of streams indicates that a considerable amount of outwashing activity has taken place even though the area now seems arid, and because in the outwash plains geologic features have become so deeply buried, presumably by deposited soil, as to be indiscernible. In the top left portion of the photograph [*E*] the presence of sandy soil is suggested by the dunelike patterns, which continue appreciably beyond the edge of the photograph. A dry lake bed [*F*] is likely to contain heavy clay soils.

The photograph is of further usefulness in determining the vegetational resources of the area. Even though the photographic scale is small, several vegetational boundaries can be seen. One of considerable significance [*H*] shows two types of grass: Mitchell grass on the left and spinifex on the right. Areas of Mitchell grass are far better than other grassland for maintaining livestock. Moreover, they normally are indicative of the most fertile soils in an area, a point of great importance if the objective is to find new land to put to the plow.

In mapping vegetational boundaries the lack of fine detail in a photograph such as the *Gemini* one may actually be helpful. The fact is evident if one looks at the area marked G in the *Gemini* photograph and at the corresponding oblique aerial photograph at the bottom left on page 56. The boundary is between mulga (a type of acacia tree) and spinifex. In the *Gemini* photograph the boundary is clear; in the oblique photograph it is difficult to follow even though more detail is discernible there.

Recently I accompanied Ray Perry of the Commonwealth Scientific and Industrial Research Organization in a check of the ground shown in the *Gemini* photograph. We made the oblique aerial photographs that appear on page 56. The check showed that the interpretations

SALTON SEA AREA of southern California appears in a photograph made from a Gemini spacecraft. The pattern is made by farmland. Individual fields as small as 40 acres can be distinguished. Many kinds of farm crops can be identified in such a photograph.

previously made from the *Gemini* photograph were correct in all respects.

I have dwelt at length on this single *Gemini* photograph in order to suggest the capabilities of spacecraft photography in the remote sensing of natural resources. Since the whole of an area as big as Australia can be depicted in a short time with a few photographs from a spacecraft, the possibilities of the technique are enormous, particularly for the vast areas of the world that are yet to be developed. Australia is a case in point. According to Australian scientists, virtually all the significant geologic, soil and vegetational features found in approximately 70 percent of the continent's arid regions are represented in the *Gemini* photograph that I have described. It seems evident that one of the best ways to produce suitable reconnaissance maps for the remainder of underdeveloped Australia and for other underdeveloped areas of the world would be through the use of space photography, supplemented as necessary with large-scale aerial photographs and with field checks.

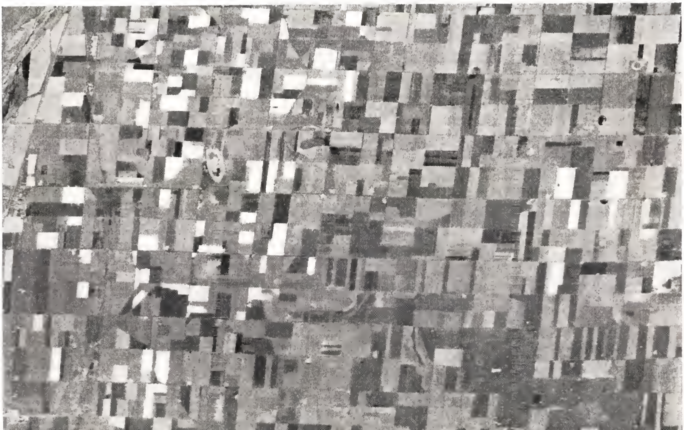
Additional Applications

The catalogue of uses for remote sensing is extensive. In forestry, for example, it is possible in small-scale photographs, such as those from spacecraft, to delineate the timberland, brushland and grassland in a wild area. With proper film and filter it is possible to differentiate the three major types of timber—hardwood, softwood and mixed wood. In larger-scale photographs one can determine the size of trees, the density of growth and the volume of timber. Foresters also use aerial photographs to detect trees that are diseased or infested with insects. Aerial photographs can be used to help in the planning of forest roads and of means for fighting forest fires.

The management of rangelands is assisted by remote sensing. From photographs one can learn the species of vegetation in an area, together with their volumes and their forage value. Photographs also reveal other data pertinent to range management, such as watering places, salt ground, plants that are poisonous to livestock, highly erodible sites and areas that need reseeding.

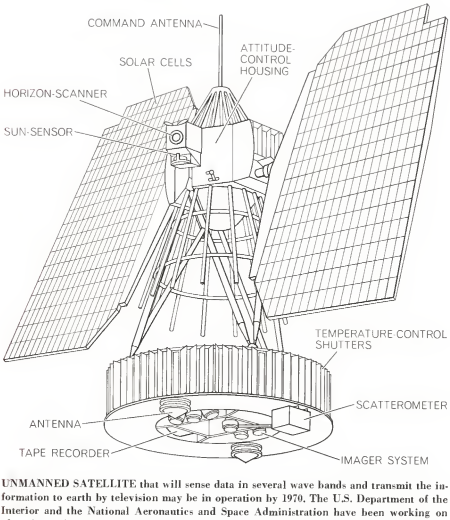
Wildlife managers can use aerial photographs for censuses of various kinds of animals and fish. The information is important in determining the impact of hunting, fishing and the works of man on fish and wildlife populations.

Administrators of agricultural programs need information on the type of crop growing in each field of a large area, the vigor of each crop and the probable yield. Where crops lack vigor, the agri-



RADAR IMAGE of farmland in Kansas shows certain types of crops more clearly than images from other bands of the spectrum could. Lightest fields, for example, contain sugar beets. Clear radar images can be obtained day and night and through clouds.

ADVANTAGE OF RADAR in penetrating a dense cover of vegetation to reveal the geologic structure of the terrain appears in a radar view of an area in the Sierra Nevada. The longer the wavelength at which radar operates, the better the radar penetrates vegetation.



UNMANNED SATELLITE that will sense data in several wave bands and transmit the information to earth by television may be in operation by 1970. The U.S. Department of the Interior and the National Aeronautics and Space Administration have been working on plans for such a spacecraft, to be known as EROS for Earth Resources Observation Satellite.

culturist wants to know what is wrong. All such information can often be obtained through the interpretation of aerial photographs if the photographs have been made under appropriate conditions, including the scale, the type of filter and film and the seasonal state of development of the crops.

Work already done along these lines has indicated that the classification of crops and land use in six categories will suffice for the preliminary assessment of almost any agricultural area. The categories are orchard crops, vine and bush crops, row crops, continuous cover (such as alfalfa and cereal crops), irrigated pasture crops and fallow ground. Each of these categories can be recognized by an experienced interpreter of photographs; usually he can also make further identifications of specific crop types within each of the six categories.

Let us consider the matter of crop vigor a little further. The first photographic evidence of loss of vigor due to black stem rust in wheat and oats or to blight on potatoes is to be found in the near infrared part of the spectrum, where reflectance rather than emission phenomena are of primary importance. On positive prints made from infrared photography the unhealthy plants register in abnormally dark tones. The technique is successful even in photographs made from spacecraft. Moreover, haze does not interfere appreciably with the technique because haze is easily penetrated by the long wavelengths used in making infrared photographs.

Water resources are susceptible to a degree of management through remote sensing. Aerial photography can show the area and depth of snowpacks on important watersheds at various times of the year. By following seasonal changes in the snowpack hydrologists can more intelligently regulate the impounding and release of water in reservoirs. Watershed managers also need to keep track of vegetation in order to estimate the loss of water to plants.

Vast ocean areas, about which a great deal remains to be learned, can be surveyed by remote sensing, particularly from spacecraft. Typically a camera in a satellite orbiting the earth can photograph a strip 3,000 miles long in 10 minutes, so that it is easily possible to keep track of changes over huge reaches of ocean. Among the phenomena that can be followed are the flow of currents, the course of tidal waves and the movements of marine animals, kelp beds and icebergs.

Many other applications of remote

sensing come to mind; I can only touch on them. Numerous archaeological sites have been discovered through conventional aerial photographs; it is probable that spacecraft photographs will reveal still more sites. Tax authorities can use aerial photographs to update maps showing land use and to spot efforts to change a land use without detection, such as by turning timberland into farmland while leaving a strip of forest along the road that a ground-based tax assessor might be expected to travel. Violations of law often show up in photographs; examples are illegal mining or logging in remote areas, pollution of waters by illegal dumping of chemicals, release through industrial smokestacks of materials that contribute to smog, and fishing in waters where fishing is prohibited. The analysis of such disasters as floods, fires and hurricanes can be assisted by the study of remote-sensing data, and the information so obtained can be used in making emergency decisions and in combating future catastrophes of a similar nature.

Techniques of remote sensing are in a fairly early stage of development. Many of the applications I have suggested are therefore yet to be realized in practice. Their success, and the achievement of still other applications, will depend heavily on further research into the kinds of data that can be obtained from remote sensing—in learning, for example, where in the spectrum a certain plant disease will appear most distinctly. My colleagues and I have found it helpful to set up arrays of various natural resources and photograph them from high but stationary places, such as water towers and the tops of cliffs. The work helps to determine, economically and under controllable conditions, the bands of the spectrum that might best be used in remote sensing directed at finding the same resources.

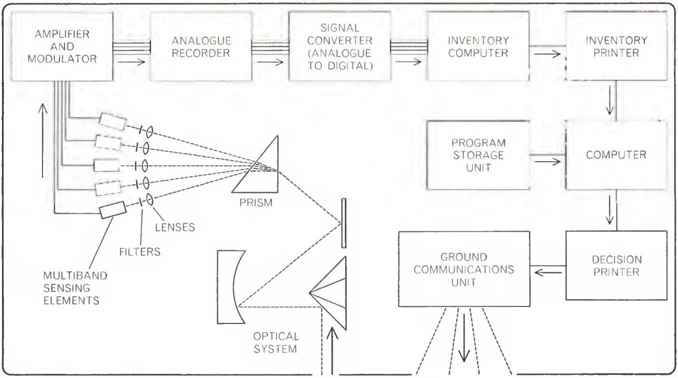
A Prospect

I can foresee the possibility that the techniques for remote sensing will evolve into a highly automatic operation, in which an unmanned satellite orbiting the earth will carry multiband sensing equipment together with a computer. Thus equipped the satellite could, for any particular area, take inventory of the resources and produce a printout that would amount to a resource map of the area. The computer could then use the inventory data in conjunction with preprogrammed factors (such as what ratio of costs to benefits would be likely to result from various resource management practices) and could reach a decision for the optimum management of the resources in the area. The decision would be telemetered to the ground for whatever action seemed necessary.

As a simple example, the satellite's sensors might spot a fire in a large forest. Its computer might then derive information on the location and extent of the fire and could assess such factors as the type and value of the timber, the direction and speed of the wind and the means of access to the fire. On the basis of the assessment the computer would send to the ground a recommendation for combating the fire.

Capabilities of this kind need not be limited to emergencies. Many routine housekeeping chores now done manually by the resource manager could be made automatic by electronic command signals. Examples might include turning on an irrigation valve when remote sensing shows that a field is becoming too dry and turning off the valve when, a few orbits later, the satellite ascertains that the field has been sufficiently watered.

A satellite of such capabilities may seem now to be a rather distant prospect. After a few more years of developing the techniques for remote sensing the prospect may well have become a reality.



COMPUTERIZED SATELLITE is a prospect for the future. It would sense resources in several wave bands, automatically identify them, weigh them against previously programmed data on the cost effectiveness of various management possibilities and send to the ground a decision on what should be done. It also could be used to monitor developing situations, such as a forest fire, suggesting how ground crews might fight it, and to perform automatically such tasks as turning irrigation valves on and off as required.

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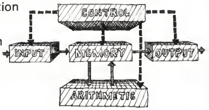

A little complexity goes a long way.

Anybody can package a potpourri of circuitry and call it MSI or LSI. But, that's not the problem. Why multiply components, when you should divide the system? Like we did. We found that sub-systems have a common tendency toward functional overlap. There are too many devices performing similar functions. More stumbling blocks than building blocks. Our remedy is a family of MSIs and LSIs with multiple applications. The Fairchild 9300 universal register, for example, can also function as a modulo counter, shift register, binary to BCD shift converter, up/down counter, serial to parallel (and parallel to serial) converter, and a half-dozen other devices.

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The *g* Factor of the Electron

It is the index of the ratio of the electron's magnetic moment to its spin angular momentum. An interesting number in its own right, its precise measurement has had far-reaching implications

by H. R. Crane

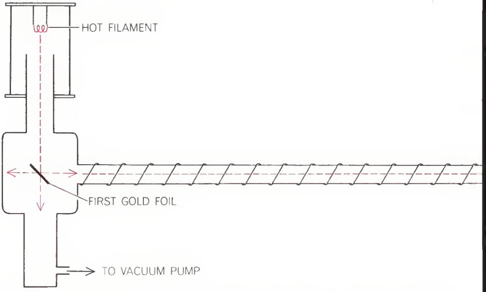
When my colleagues and I at the University of Michigan started our experiments on the g factor of the electron in 1950, we had no idea we would still be at it 17 years later. But now the sixth in a succession of Ph.D. students is beginning his work. It has been a leisurely, drawn-out affair. We seem to have been allowed to occupy a little corner of physics pretty much by ourselves—a privilege generally reserved to those who work on projects that are regarded as too hard, too tedious or of too little importance to be worthwhile game for competition. When we think that the results of more than 50 man-years of our labor and half a million dollars could probably be written in the margin of a postage stamp, it is not surprising that most people have been glad to see that kind of work done by someone else. The accidents that got us started, the shifts we had to make in our attack at several points along the road and the way everything worked out not as we had planned but much better than we had planned makes an interesting case history.

I shall include in this account as many of the uncertainties and human errors that beset us as I can recall. I could instead make it sound as if we knew exactly what we wanted to do at all times, but I shall save my talents along these lines for the writing of applications for funds or articles for physics journals. It seems to me that science is more interesting the way it is actually done, and that is the side of our adventures I want to show here.

The g factor is a number that might be applied to any spinning object with a magnetic moment parallel to its axis of rotation. (In everyday language the magnetic moment of, say, a bar magnet or a compass needle is simply its strength. The direction of the magnetic moment is along the line connecting the two poles.) The earth almost conforms to this description, and it would conform exactly if its north and south magnetic poles were not slightly out of line with respect to its north and south geographic poles.

If a spinning object with these properties is placed in an external magnetic field (a field other than the one due to the object's own magnetic moment), it will "precess" like a spinning top or a gyroscope, that is, its axis of rotation will slowly move around in a cone. The frequency of the precession will depend on the product of two factors: the strength of the external magnetic field and the ratio of the object's magnetic moment to its angular momentum of rotation. (The angular momentum of an object is its "amount" of rotation. For a wheel it would depend on the speed of rotation, the mass of the wheel and the way the mass is distributed in the wheel.)

Although the external magnetic field is at the disposal of the experimenter and can be made to have any desired strength, the ratio I have just mentioned (magnetic moment to angular momentum) is a property of the spinning object itself. This ratio has a unique value for the electron and is quite the same for every electron in the universe. Other kinds of particles (for example the proton) have their own unique ratios. Since only the ratios for the various particles, and not the separate values of the angular momentum and magnetic moment,



ORIGINAL APPARATUS built by the author and his colleagues at the University of Michigan was designed to study the polarization, or degree of parallel alignment, of the spin axes of the electrons in a high-energy electron beam by means of the double-scattering technique (*see illustration on page 74*). To avoid the possibility that X rays and electrical disturbance produced by the electron source would interfere with the counting of the electrons,

are needed for interpreting many phenomena, the measurement of the ratios to a high accuracy has been the object of intensive research. The *g* factor of a particle is the index of that ratio.

So far I have indicated why the *g* factors of particles are interesting numbers, but I have given no hint as to why the *g* factor of the electron in particular has been the yeast in more than one significant revolution in physics. For that part of the story I must go back more than 50 years and begin with Niels Bohr's original model of the hydrogen atom.

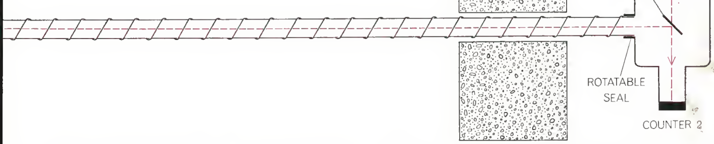
Following the spectacular success of Bohr's model in accounting for the lines in the hydrogen spectrum, it became apparent that the spectra of atoms of higher atomic number had complexities that would require for their explanation more descriptive factors (called quantum numbers) than were contained in the original model. This was strikingly shown by the "anomalous Zeeman effect" in the alkali atoms (such as the atoms of lithium and sodium). The Dutch physicist Pieter Zeeman had shown that when atoms were subjected to a magnetic field while radiating light, the normal lines were split into multiple lines that lay close together but remained sharp and distinct. If the magnetic field had merely shifted the wavelengths of the lines a little one way or the other, that would not have been surprising. After all, the electron circulating in its orbit around the atomic nucleus is equivalent to a current flowing around a loop of wire. Such a loop of current gives rise to a magnetic moment—a north and south pole if you like. Accordingly it would have been reasonable to have expected an external magnetic field to have a modifying effect on the electron orbits. What could not be understood at all on the basis of the Bohr model was that in the presence of a magnetic field single lines were split into two or more distinct lines.

It was this puzzle that led two young Dutch physicists, Samuel A. Goudsmit and George E. Uhlenbeck, to postulate in 1925 that the electron itself had an angular momentum and a magnetic moment. In a recent speech before the American Physical Society, Goudsmit recalled that it was he who had arrived at the conclusion that an additional quantum number, necessary to give the added complexity in the spectra, probably was to be associated with the electron, whereas it was Uhlenbeck who had seen that the new property would have to be of the nature of an intrinsic angular momentum. Thus was born the concept of electron spin.

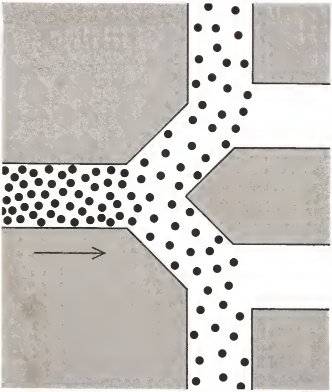
That the electron should have in addition an intrinsic magnetic moment was part and parcel of the idea that it was spinning. Any charged, rotating body would, by the simple concept of a circulating current, be expected to have a magnetic moment. It was a daring hypothesis, by no means immediately accepted. The spin gave the additional quantum number required to explain the splitting of the lines in the spectra. In fitting the values of the electron's angular momentum and magnetic moment to conform to the experiments on the anomalous Zeeman effect, Goudsmit and Uhlenbeck found a strikingly simple relation. The electron's intrinsic angular momentum had to be exactly half the angular momentum of the orbital motion of an electron in its lowest Bohr orbit in the hydrogen atom, or $\hbar/2$, where $\hbar$ is short for Planck's constant (h) divided by 2π. The intrinsic magnetic moment had to be equal to that produced by the orbital circulation of an electron in its lowest orbit in the hydrogen atom. The latter quantity, called the Bohr magneton, is $e\hbar/2mc$, where e and m are the charge and mass of the electron and c is the velocity of light [*see illustration on page 79*].

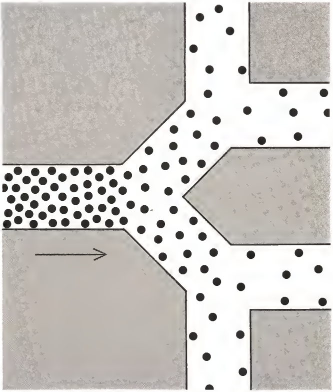
Thus at the time of the discovery of electron spin the *g* factor of the electron could be expressed as the number of "natural units" of magnetic moment ($e\hbar/2mc$) divided by the number of "natural units" of angular momentum ($\hbar$). When defined in this way, the *g* factor for the orbital motion of the electron in its lowest energy state in hydrogen is 1, whereas the *g* factor of the free electron is 2. (The *g* factor as a term designating a ratio of magnetic moment to angular momentum in these special units had been introduced a few years earlier for the case of the atom by the German physicist Alfred Landé.)

There being no reasons to the contrary, the relations given above were



the site of the second scattering was located in the next room at a distance of about 30 feet. When the first tests were made, however, too few electrons arrived at the second scatterer, because the beam tended to fan out in the 30-foot pipe. A layer of current-carrying wire was therefore added to the outside of the pipe in order to establish a magnetic field in the pipe parallel to its axis; this focuses the electrons and also causes their axes of spin to precess slowly. When the use of a magnetic field was first considered, it became apparent that by measuring the amount by which the spin axes precessed it might be possible to determine the electron's *g* factor.





DOUBLE-SCATTERING TECHNIQUE is at the root of the *g*-factor experiments. In order to polarize a beam of electrons whose axes of spin point randomly in all directions, all one needs is a sorting mechanism, so that one can keep the ones that are pointing in a particular direction and discard the rest. To get an observable effect, however, one must do the sorting twice. At the first sorter equal numbers will be deflected to the right and to the left. Actually the direction in which a particular electron is deflected depends in part on whether its north pole is pointing up or down. This effect is not yet observable, however, since the equal division of the beam could be due to pure chance. It takes a repetition of the scattering process to bring out the result of the sorting in an observable way. A 100 percent inequality after the second sorting is shown at left for clarity; in actuality the inequality of the beams is at best only about 6 percent. If the two sortings were due only to chance, the beams after the second sorting would still be equal (*right*).

taken to be exact, and they stood unquestioned for about 20 years. In physics there are good reasons for assuming that simple relations are exact until it is proved otherwise. There are many of them that do hold, and this is one of the reasons why some people find beauty in the subject. In the case of the *g* factor of the electron, a strong reinforcement for the belief in the exactness of the value 2 came in the late 1920's from the new formulation of quantum mechanics by P. A. M. Dirac. In his formulation Dirac did not "put in" a *g* factor of 2 as a requirement of a model of the electron. He applied the basic laws of physics (including relativity) according to a simple set of conditions, and the *g* factor of exactly 2 "came out." After World War II, however, this situation began to change.

In the first few years after the war some striking experimental and theoretical developments occurred that led to what is now called the new quantum electrodynamics. A central part of this work involved taking into account the interaction of the electron with the empty space around it, or with what physicists call the "vacuum." If it seems strange to say that empty space could have an effect on the electron, it is because one tends to think of empty space in the ordinary sense of its being devoid of gross objects such as gas molecules. In the context of the subatomic world, however, empty space is by no means devoid of properties. There can be the creation and annihilation of electron pairs and other kinds of particle pairs, local fluctuations of electric and magnetic fields, and of course the propagation of radiant energy. When in the new quantum electrodynamics the effect of empty space on the electron was properly accounted for, the result was an increase in the *g* factor to slightly more than 2. In itself the change in the *g* factor does not sound very startling. But the whole development was a profound one, as attested by the fact that five of the people most closely involved were awarded Nobel prizes: Willis Lamb and Polykarp Kusch in 1955 (for experimental work), and Julian Schwinger, Richard Feynman and Sin-Itiro Tomonaga in 1965 (for theoretical work).

It would be impossible, without devoting the entire article to it, to trace this development in any detail. There are, however, some comments I should like to make. The term "new quantum electrodynamics" does not imply that the existing theory was junked in favor of the new theory. The new theory was rather an extension of the existing theory, which had stopped short of including the interaction of the particles with the vacuum. Theorists had been trying to include it, but the formulas came out containing infinite terms, which could not be got rid of by the accepted theoretical methods, and so the matter had hung in the limbo of speculation. But when experimental results suddenly began appearing that did not agree with the existing theory and that gave actual numbers against which attempted solutions could be tested, progress became quite rapid. A way that had been proposed earlier for circumventing the infinities proved itself by giving answers that were consistent with the experiments. The methods were still not unquestioned; for example, as Dirac later remarked in *Scientific American* (May, 1963), he could not help looking on the

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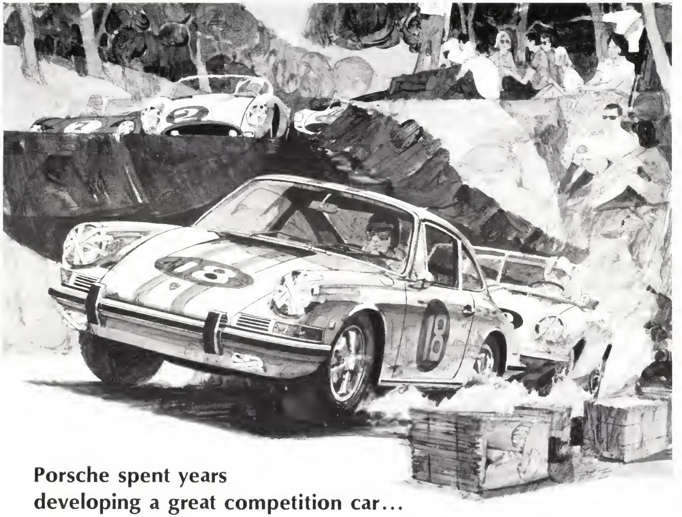

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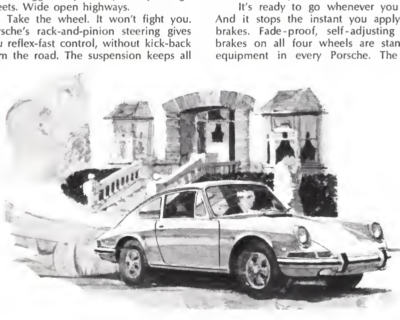

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solution of the problem of the infinities as a "fluke." I suppose he meant that a method that evidently worked in a particular application should still be held questionable as to its generality.

This, then, is where things stood in 1950, when we embarked on our g-factor measurements. There had been a shake-up. The new theory gave a g factor of the electron about .1 percent larger than 2, and there were experimental results that were in agreement, within modest limits of accuracy. Because the new theory was based on unconventional methods, its acceptance rested on a pragmatic basis. A measurement of the g factor to a much greater precision would be more than just a routine verification; it would be one of the critical tests of the new theory. If at that point we had taken up our experiments in answer to this clarion call, the story would read as a story is supposed to read. That is not the way we got into it at all. We backed into it. Here is what really happened.

	ORBITAL ELECTRON	FREE ELECTRON
ANGULAR MOMENTUM	$\hbar$	$1/2\,\hbar$
MAGNETIC MOMENT	$\frac{e\hbar}{2mc}$	$\frac{e\hbar}{2mc}$
MAGNETIC MOMENT / ANGULAR MOMENTUM	$\frac{e}{2mc}$	$\frac{e}{mc}$
g FACTOR	1	2

g FACTOR OF THE ELECTRON was defined at the time of the discovery of electron spin (1925) as the number of "natural units" of magnetic moment ($e\hbar/2mc$) divided by the number of "natural units" of angular momentum ($\hbar$). When defined in this way, the g factor for the orbital motion of the electron in its lowest energy state in hydrogen is 1, whereas the g factor of the free electron is 2. These relations were taken to be exact for about 20 years.

We had begun in 1946 a project of designing and building one of the largest electron accelerators of that time, which we called the "racetrack" synchrotron. The project presented a series of problems that had to be worked out as we went along. Meanwhile graduate students were working on the project who did not have forever to wait for the synchrotron to operate in order to do their thesis problems and get their Ph.D.'s. One of these students was William H. Louisell, who has since joined the faculty of the University of Southern California. Robert W. Pidd (now at Gulf General Atomic Inc.), one of several professors associated with the synchrotron project, was chairman of Louisell's doctoral committee, and I was a member. We decided to try to define a thesis problem that would use not the entire synchrotron but just the parts that were finished at that time. One part that was finished was the "electron gun," a high-voltage vacuum tube that could produce an intense beam of electrons at energies of up to 600,000 electron volts. Its purpose was to inject the electrons into the synchrotron, where they were to be further accelerated up to 300 million electron volts. Before becoming involved in building the synchrotron, both Pidd and I had had an interest in polarization effects in electron beams, as studied through double-scattering experiments. We thought that the electron gun of the synchrotron would be an ideal tool for such experiments. Accordingly we put our interests and our available tools together and came up with a thesis problem for Louisell.

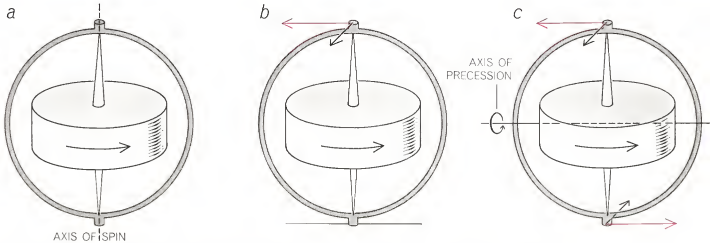
At this point I should like to elaborate a bit on double scattering, a technique that in addition to being basic to our own experiments has a broad application in physics. Electrons that are emitted from a hot filament have their axes of spin pointing randomly in all directions. If some of these electrons are accelerated and formed into a beam, the beam is said to be unpolarized. In order to polarize the beam it is not necessary to turn the electrons so that their north poles all point in the same direction; in fact, we know no way of doing that. If there are plenty of electrons to spare, all one needs is a sorting mechanism, so that one can keep the ones that are pointing in a particular direction and get rid of the rest. We do know how to make a sorter. Curiously enough, in order to have an observable effect it is necessary to do the sorting twice. Hence the term double scattering.

I shall use a simple analogy to show why two sorters are necessary. Suppose we make 1,000 small cards, of which 500 say "Always take the right turn" and 500 say "Always take the left turn." We shuffle the cards and give one to each of 1,000 motorcycle riders, who have agreed to cooperate. Each reads his card and puts it in his pocket, and they all start down a road. After the first fork in the road, does an outside observer see any effect traceable to the cards? No. He sees only that 500 motorcycles have taken each road at the first fork, which could be due to pure chance. The observer must wait until the second fork to see the effect. The effect is then dramatic. Those traveling on the road that went to the right at the first fork will now all take the right-hand road at the second fork. Similarly, those on the other road will all turn to the left. In the language of electron scattering, the first fork is the polarizer and the second the analyzer. Not until after the motorcycles have passed the analyzer does the observer have visible evidence that sorting has been accomplished [*see illustration on page 74*].

An electron doesn't carry a card, but it may have its north pole up or it may have it down, and that makes it belong to one class or the other. If one shoots a beam of electrons through a thin piece of material, say a gold foil, many electrons will be deflected to the right and to the left. The two classes (north pole up and north pole down) will have been sorted as were the motorcycles at the first fork of the road, but the fact will not yet be observable. It will take a repetition of the scattering process, performed on either the right or the left beam, to bring out the result of the sorting in an observable way. When the electrons pass through the second gold foil and are scattered—this time unequally between right and left—under the best conditions the inequality is only about 6 percent. The sorting is by no means as perfect as it was in the example of the motorcyclists, but it is good enough to make an experiment possible.

The theory of the double scattering of electrons was put forward by N. F. Mott in 1929, and the process goes by his name. Surprisingly, about six years passed before anyone succeeded in producing the effect experimentally, and even in 1950, when Louisell undertook to study the effect, little had been found out about it in a quantitative way. That is why the double-scattering of electrons looked like a good thesis problem.

The synchrotron injector that was to be used for the electron source was in



MODEL OF A SPINNING ELECTRON, consisting of a piece of wine-bottle cork with a toothpick stuck through it and some negative electric charge on the cylindrical surface, turns out to have a *g* factor of 2. The amount of charge and the mass of the cork must be in the same ratio as the charge and mass of an electron. When the model is spinning (*a*), the ratio of its magnetic moment to angular momentum is e/mc, which is a *g* factor of 2, regardless of the speed of spinning, and regardless of the size or the length-to-diameter ratio of the cork. Such a model behaves as a gyroscope. If one gently pushes the top of the toothpick sideways (*b*), it will refuse to go that way but will go in a direction at right angles to the direction of the force. If the model is spinning in open space and opposite forces are applied to the ends of the toothpick from the left and the right (*c*), one end will come forward and the other end will go backward. It is this turning of the spin axis that is termed precession. Now, if the model is placed in a magnetic field (*d*), the

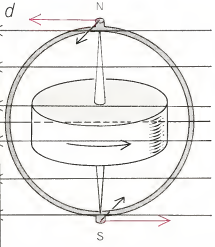
the main synchrotron room. When the injector was running, it produced a high level of X rays and electrical disturbance, and we knew this would interfere with the detecting and counting of the electrons after the second scattering process. We therefore elected to locate the site of the second scattering some distance away, in fact in the next room at a distance of about 30 feet. We provided an evacuated pipe for the electrons to travel through [*see illustration on pages 72 and 73*]. We were perhaps unduly attracted to this scheme because the wall separating the rooms was made of concrete three feet thick and it already had a porthole in the right place. The arrangement seemed ideal. When the vacuum pipe was in place and the first tests were made, however, we found that far too few electrons arrived at the second foil, simply because the electron beam tended to fan out in the 30 feet between the targets.

A standard method of focusing the electrons from one end of a pipe to the other is to establish a magnetic field in the pipe parallel to its axis. All that is required is a layer of wire on the outside of the pipe with current in it. I suggested this was a way of conserving our electrons, but immediately caught myself and asked: "What would the magnetic field do to the polarization?" (The electrons traveling down the pipe were presumably polarized as a result of the sorting by the first gold foil.) It did not take us long to decide that if the electrons behaved like spinning magnets, the effect of the magnetic field on them would be to cause their axes of spin to precess slowly, just as the axis of a toy top precesses while it is spinning on the pavement. The orientation of the axis of spin would be altered before the electrons arrived at the second foil. It was clear that if such a precession did occur, and if we could measure the change in the direction of the spin axis, we would have a way of determining the value of the magnetic moment—a much more interesting pursuit than the one we had originally started with. But would electrons really behave that way? Mechanical models are powerful tools for thinking (some of us—I for one—would be lost without them); however, one has to be exceedingly cautious in using them in the realm of the very small, where quantum effects become overriding, to make sure at every turn that one is not asking the model to perform in ways that are in conflict with quantum principles. It was at this point that our theorist colleagues began flashing yellow caution lights at us—with good reason.

A mechanical model of the spinning electron—even though suspect—has some intriguing properties, which I should like to describe here. A model of the spinning electron made in about the simplest possible way turns out to have the g factor given by the Dirac equation, namely 2. Take any solid right circular cylinder, such as a wine-bottle cork, and stick a toothpick through its ends [*see illustration above*]. Then put some negative electric charge on the cylinder's surface but none on the ends. The amount of charge and the mass of the cork must be in the same ratio as the charge and mass of an electron. Now, when the cork is spun on the toothpick as an axle, the charge, moving around in a circle, acts as a loop of current and gives the model a magnetic moment. In addition the rotating cork has angular momentum. The ratio of the magnetic moment to the angular momentum of this model is e/mc, which is a g factor of 2, regardless of the speed of spinning, and regardless of the size or the length-to-diameter ratio of the cork! (It might appear that a still simpler model would be a cork ball, but that would not have a g factor of 2.)

The model behaves as a gyroscope. If one sets it spinning vertically and gently pushes the top of the toothpick sideways, it will refuse to go that way but will go in a direction at right angles to the direction of the force. If the model is spinning in open space and opposite forces are applied to the ends of the toothpick from the left and the right, one end of the toothpick will come forward and the other end will go backward; the model will keep turning in this way, making several complete revolutions. It is this turning of the axis (in contrast to the rotation of the cork) that is termed precession. The tips of the toothpick never do move in the directions in which they are being pushed.

Now, if the spinning-magnet model is placed in a magnetic field, the north pole will be pulled one way along the field lines and the south pole the other way. The axis of spin will turn in the manner of the gyroscope, and the num-



north pole will be pulled one way along the field lines and the south pole the other way. The axis of spin will turn in the manner of the gyroscope, and the number of complete turns it will make per second will be proportional to the *g* factor and the strength of the applied field. In the original apparatus there were about five full turns in 30 feet.

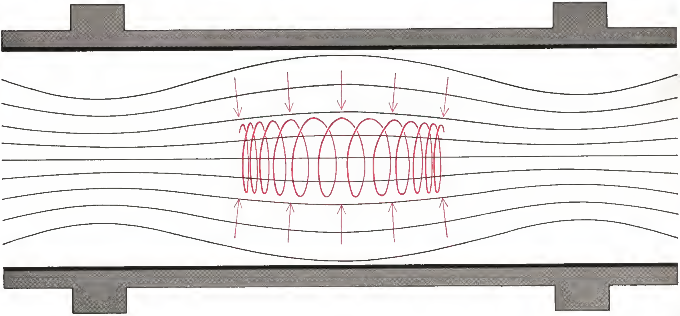
ber of complete turns it will make per second will be proportional to the g factor and to the strength of the applied magnetic field. In Louisell's apparatus there would be about five full turns of the spin axis while the electrons were going the 30 feet down the pipe. He would have only to measure the exact amount of turning in order to solve for the g factor—if the experiment would work at all! Many physicists held strong reservations about it.

The doubts that our experiment would work were prompted by some arguments that had been put forward by Bohr in a lecture in the 1920's. At the time only two experiments by which one might attempt to observe the magnetic moment of the free electron had been imagined. One was to detect the magnetic field of the electron directly, by means of a sensitive magnetometer; the other was to sort electrons as to the orientations of their magnetic moments by sending a beam of them through a nonuniform magnetic field. Bohr had demolished both schemes by subjecting them to the test of the Heisenberg uncertainty principle, which states that there is a natural limitation on the precision with which the position and the linear momentum of a particle can be known simultaneously. Both schemes, if they were to work, would require measuring these quantities to greater than the possible precision.

Bohr's calculations were back-of-the-envelope type: simple and unequivocal. The mistake was made not by Bohr in his proofs but in the sweeping generalization that was subsequently made of them by others. It was, in effect, that no experiment to measure the magnetic moment of the free electron directly could succeed, by reason of the uncertainty principle. This got into the textbooks and became, one might say, gospel. When, more than two decades later, we proposed an experiment to measure the precession of the free electron, an experiment that in fact did not require the simultaneous knowledge of the position and linear momentum of the particle beyond the limits prescribed by the uncertainty principle, it was this old belief that no experiment whatever could work that we encountered head on.

I can recount an incident that is amusing in retrospect to show the firmness of the conviction that experiments on the magnetic moment were not possible. At the meeting of the American Physical Society in Washington in April, 1953, Louisell presented his first successful measurement, and two theorists in our department, Kenneth Case and Harold Mendlowitz, presented proof that the concept of the experiment was in harmony with quantum mechanics. Yet the evidence was not persuasive to several physicists in the audience, who rose to cite the Bohr proofs to us. The person who voiced the strongest objection said later that when he was halfway home on the airplane he satisfied himself that there was no conflict between our experiment and what Bohr had shown!

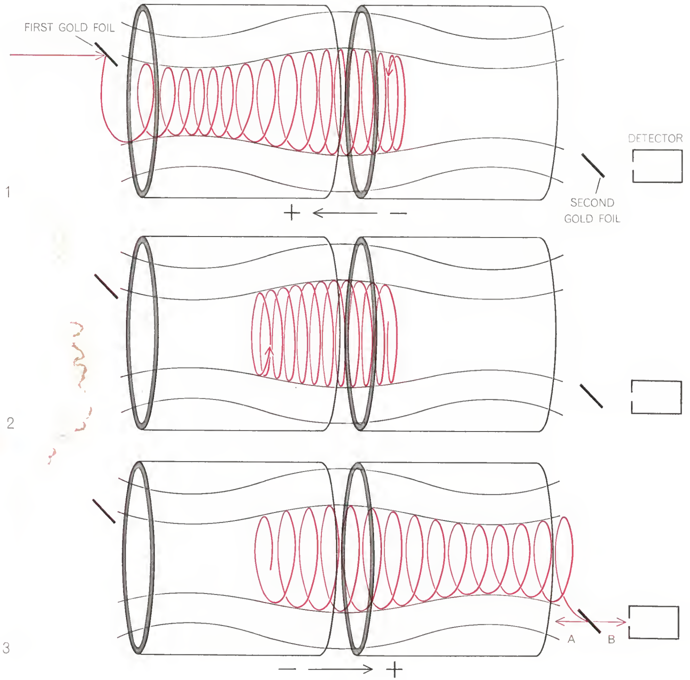
By the time Louisell had his experiment under way we realized that the number of revolutions of the precession that would occur in his 30-foot pipe would be far too few. There would be only five. If we were to get many more revolutions by extending the pipe, however, it would reach to the next town. I was able to devise a change in the arrangement that would overcome this



MAGNETIC BOTTLE consists of an empty space in which there is a magnetic field that is a little stronger at each end than in the middle, so that the lines of force (*black*) pinch together to form necks. A particle trapped in such a bottle moves in a helical path (*color*) around the axis of symmetry of the field. When the particle approaches one of the necks, it is always turned back toward the center of the bottle, because the force acting on the particle, being at right angles to the field lines, has a component toward the center.

limitation, not for Louisell's experiment—he could hardly be asked to start over again—but for the next experiment and the next graduate student. The new scheme makes use of what is commonly called a magnetic bottle [*see illustration on preceding page*]. The correct analogy here would actually be a bottle with a neck at each end, since such a device consists of an empty space in which there is a magnetic field that is a little stronger at each end than in the middle, so that the lines of force pinch together to form two necks.

A particle trapped in such a bottle moves in nearly circular motion around the axis of symmetry of the field. The motion is not exactly circular; it is helical, with closely spaced turns. The particle progresses slowly back and forth trying to get out first one neck of the



MAGNETIC BOTTLE IS USED to obtain many more revolutions of the precession of the spin axis of the electron in the *g*-factor experiment without extending the length of the apparatus unreasonably. In step *1* electrons scattered from the first gold foil barely make it through the neck into the bottle. When they pass from the positively charged metal can (+) to the negatively charged one (−), they lose some of their axial velocity. Therefore they fail to make it out the right end of the bottle and are turned back. In step *2* the electrons have moved back to the left end of the bottle, but they have not regained their lost axial velocity, because the charges on the cans had been removed before the electrons started their return trip. They therefore do not have enough axial velocity to escape from the left end of the bottle. They are temporarily trapped in the bottle. In step *3* the charges are put back on the cans again, but with the opposite polarity. As a result the electrons now gain some axial velocity going from left to right. This enables them to escape through the right neck of the bottle and hit the second gold foil. Some are scattered in direction *A* and some in direction *B*. The relative numbers in these two directions reveal their polarization. Only the ones going in direction *B* are counted.

bottle and then the other. It is always turned back toward the center of the bottle, however, because the force, being at right angles to the field lines, has a component toward the center. In the new scheme the electron gun and first scatterer are placed so that the electrons that have been scattered at 90 degrees by the scatterer are traveling in just the right direction to begin the helical path.

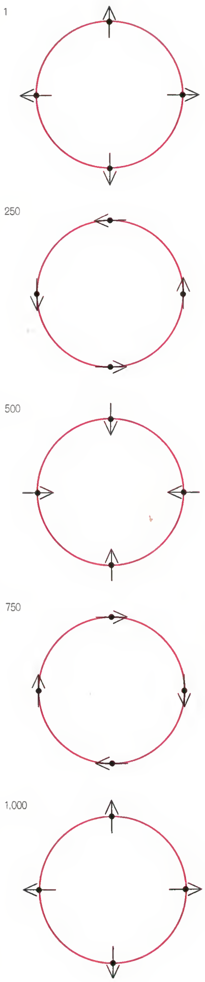
Catching some electrons in the trap, letting them out and getting them through the analyzer to the final counter is not simple. The complete sequence of events takes place within 100 microseconds (millionths of a second) or so [*see illustration on opposite page*]. First the electron gun turns on for .1 microsecond, letting a burst of electrons strike the first scatterer, which consists of a piece of gold foil. About 10 billion electrons hit the foil. Only about 100,000 are scattered by the gold nuclei in just the right direction to follow the helical path required for entrance into the bottle.

At this point we have the problem of catching these 100,000 electrons so that they will stay in the bottle. It is a problem because those that have enough axial velocity to be able to get through the neck into the bottle will for the same reason be able to pass through the neck again at one end or the other and escape. Some of the axial velocity has to be removed after they get in. Accordingly while the swarm of electrons is making its first pass through the center of the bottle, we put the brakes on by applying a retarding electric field in the direction of the axis of the bottle. With their axial velocity reduced the electrons do not escape at the right end; they turn around and come back toward the left end. But at about the time they turn around the electric field is removed, so that in moving from right to left they do not regain their lost axial velocity. They therefore cannot escape at the left end and are trapped. From that time on they move in a helical path with very closely spaced turns, progressing slowly back and forth between the ends of the bottle.

After imprisonment for a period of our choosing, we again apply the electric field, but this time in such a direction as to speed them up toward the right. They easily clear the right neck of the bottle and after a few more turns strike the gold foil of the second scatterer. At the second scatterer the number of electrons that get scattered in the desired direction is again a very small fraction of the number striking the foil. If all the 100,000 trapped electrons hit the second scatterer, only one or fewer than one, on the average, is scattered at the correct angle to strike the final counter. This may sound highly inefficient, and so it is, but the entire cycle I have just described is repeated about 1,000 times per second. The counting rate is therefore on the order of a few hundred per second. The whole process of course works automatically by electronic timing circuits. I might add that an electron trapped in this system for 100 microseconds precesses as many revolutions as it would in traveling through a straight pipe six miles long!

The new scheme gives us another advantage, separate and distinct from the increased number of revolutions. This advantage lies in the fact that the spin axis precesses through almost exactly a complete turn while the electron makes one lap around its helical path. If the g factor were exactly 2, the two motions would keep in step exactly. We therefore need only to measure the small amount by which the two rotation rates differ in order to find out how much the g factor differs from 2. In this way we get far more precision than we would if we were to measure the spin precession rate by itself, because the difference in the two rates is only about a thousandth of the rate of the precession.

To see how the two rotations combine, consider the situation for an electron at different times after it starts its captivity in the bottle [*see illustration at right*]. Owing to the sorting by the first scatterer the electrons that start the helical motion have their spin axes pointing radially away from the common axis of the helix and the bottle. Because the two rotations of each electron are so nearly equal, the spin-direction arrow during the first orbital revolution appears to turn as if it were painted on the rim of a wheel. A few hundred revolutions later, however, the rotation of the spin axis has gained perceptibly on the orbital rotation, and it no longer points in



ANOTHER ADVANTAGE of the magnetic-bottle version of the *g*-factor experiment lies in the fact that the spin axis of the electron (*small arrows*) precesses through almost exactly a complete turn while the electron makes one lap around its helical path (*large circles*). If the *g* factor were exactly 2, the two motions would keep in step exactly. By measuring the small amount by which the two rotation rates differ, therefore, one can find out by how much the *g* factor is greater than 2. The spin axis returns to its original orientation after completing about 1,000 laps (*bottom*). The view is along the common axis of the helix and the bottle.

the radial direction. The spin direction continues to gain until after about 1,000 revolutions it has gained a full revolution on the orbital motion and is back in its original orientation. Obviously if the electron were let out of the trap after approximately 1,000, 2,000 or 3,000 revolutions, it would have the same spin orientation as it started with, and if it were let out after 500, 1,500 or 2,500 revolutions, it would have the opposite spin orientation.

The electrons, after they are let out of the trap, strike the second scatterer (also a gold foil). The chance of the electrons' being deflected along a given path depends on the spin orientation. Actually only the ones that go along one direction are counted. The count is alternately maximum and minimum when the number of revolutions has been 0, 500, 1,000, 1,500 and so on. (I have used round numbers here for illustration; the maxima and minima are not exactly multiples of 1,000, and determination of the exact number is the purpose of the whole experiment.) In actual practice we look for the maxima and minima in terms of the length of time the electron has spent in the bottle, rather than in terms of the number of orbital revolutions it has made. Either way would give the result we are after, but doing it in terms of the time is more convenient.

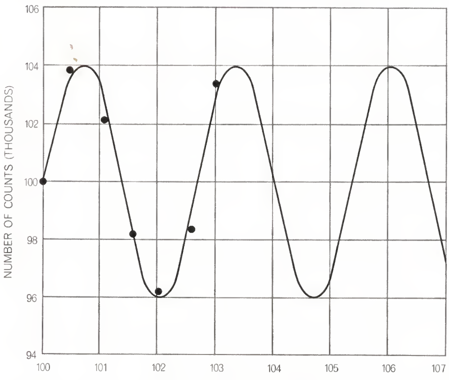
I have mentioned that the time of captivity in the trap can be set to any value we choose. Suppose we set the timing circuits so that each injected batch of electrons is held in the trap for 100 microseconds. The whole process therefore repeats 1,000 times per second. Say we run for 10 minutes (some 600,000 batches) and record the total number of counts of the detector (about 100,000). Next we move the trapping time up to 100.5 microseconds and make another 10-minute run; then we move up to 101 microseconds, and so on. The number of counts for each 10-minute measurement interval is now plotted against the length of time the batch of electrons was held in the trap [*see illustration below*]. To get from one maximum to the next we have to increase the time in the trap by about 2.6 microseconds, which means about 1,000 additional revolutions of the electron's helical motion. To get the time separation between the maxima in the curve with the greatest possible accuracy, which is the crux of the experiment, we take data over a time range that includes several hundred maxima and minima, and determine the average value.

Such measurements do not yield the g factor of the electron directly. Instead they give a value for what is called the g-factor anomaly—which is equal to half the amount by which the actual g factor exceeds 2. This anomaly is inversely proportional to the time between the maxima in the curve that represents the experimental results. Since the anomaly is nearly 1,000 times smaller than the g factor, however, this means that our measurement has, you might say, a head start on accuracy by a factor of nearly 1,000. If we measure the anomaly to a part in 100,000, we will get the g factor to about a part in 100 million.

The first experiment along the lines I have just described was done by Arthur A. Schupp, the graduate student who followed Louisell. When he started, we moved from the subbasement to the top floor of the building (by that time the synchrotron needed its electron gun) and built new apparatus. This took a lot of development work, because it was the first attempt to use the new method involving the magnetic bottle. Schupp was unbelievably persistent, and when all the problems were solved he came out with an answer for the g factor that was accurate to a few parts in 10 million.

As in many experiments, by the time Schupp was through with his measurements (soon after receiving his Ph.D. he joined the General Dynamics Corporation) we knew of many improvements that could be made. So when the next graduate student, David T. Wilkinson, took over, he started by tearing down the parts of the equipment that most needed improving. He could find no stopping place before he had passed the point of no return. The entirely new apparatus he built was not different in principle, but it incorporated many features that enhanced the reliability and accuracy. Wilkinson's result went two decimal places beyond that of the previous result. He found g equal to $2.002319244 \pm .000000054$. This was, and still is, one of the most precise measurements in all physics. The theoretical calculation gave 2.002319230. So far, to this degree of accuracy, theory is substantiated. But neither we nor the theorists want to let it rest there. We are therefore exploring other means, and a new graduate student, John Wesley, is well along in developing a new experiment.

Before Wilkinson left the project to join the faculty of Princeton Univer-



SINE CURVE relates the number of counts recorded in the detector in a 10-minute interval to the length of time each batch of electrons was trapped in the bottle before being let out. The electrons make approximately 1,000 revolutions in their helical motion from one peak to the next. In practice, of course, the data points do not fall perfectly on the sine curve, because in a finite number of counts there is an element of chance. The crux of the experiment is to determine the average time separation between the peaks in the curve with the greatest possible accuracy, taking data over a time range that includes hundreds of peaks.

sity, he and the next graduate student, Arthur Rich (now on the Michigan faculty), turned their attention to the possibility of measuring the g factor of the positron. The positron is the electron of antimatter, the oppositely charged twin of the electron. In our world the positron exists only briefly before combining with an electron in mutual annihilation, converting matter into radiant energy. Positrons for the g-factor experiment are obtained from a radioactive emitter. The main part of the experiment—trapping the particles in a magnetic bottle—follows the general scheme used for the electron. The polarization and analysis are done differently, however. The experiment is extremely difficult because of the small number of positrons available. Nevertheless, Rich has been able to obtain a value for the g factor of the positron that is accurate to a part in 100,000. It agrees with the value found for the electron. John Gilleland, another graduate student, is now preparing a measurement in which he hopes to improve on that accuracy.

One might ask why it is important to measure the g factor of the positron if we believe it is the exact twin of the electron. It is true that we do not expect to find a different result for the positron, probably to the greatest degree of accuracy we can ever reach, but we should not take it for granted. The questions of symmetries in nature, of which this is an example, have become very subtle and are not yet fully understood. There is abundant evidence that not only the electron but also every other kind of charged particle will be found to have an opposite twin. A great many twins have been produced and studied. One therefore can visualize an antimatter world, made entirely of these opposite particles [see "Antimatter and Cosmology," by Hannes Alfvén; SCIENTIFIC AMERICAN, April, 1967]. In this sense the electron is a citizen of our world and the positron is a foreigner. As I stated earlier, the anomaly in the g factor is related to the coupling of the electron with the world it is in. The extension of this thought raises an amusing question: Would we expect to find exactly the same g factor for the electron and the positron only if each were in its own world? To settle the issue would require that we do the electron experiment in a matter world and the positron experiment in an antimatter world. But where can we find an antimatter graduate student who will go to an antimatter world and make the measurement?

THE VENOUS SYSTEM

The veins constitute a reservoir for the blood supply, not merely a system of passive conduits. They constrict and dilate actively, thus maintaining a satisfactory distribution of blood in the body

by J. Edwin Wood

The concept of the veins as passive conduits, fitted with valves to permit the flow of blood only toward the heart, was developed by William Harvey in the 17th century and persisted until fairly recently. In the past two decades, however, it has become clear that the veins have more subtle functions. Experiments showed first that the veins are capable of being distended far more than the arteries and then that at any given time they contain most of the blood in the body—perhaps 70 percent of the total. This suggested that they are not only conduits but also "capacity vessels," and that if this is true large quantities of blood must often accumulate in the lower parts of the body. This in turn made it seem likely that under such circumstances as exercise, blood loss or heart failure the veins must have to function actively in order to maintain venous blood pressure and perhaps to redistribute the blood supply.

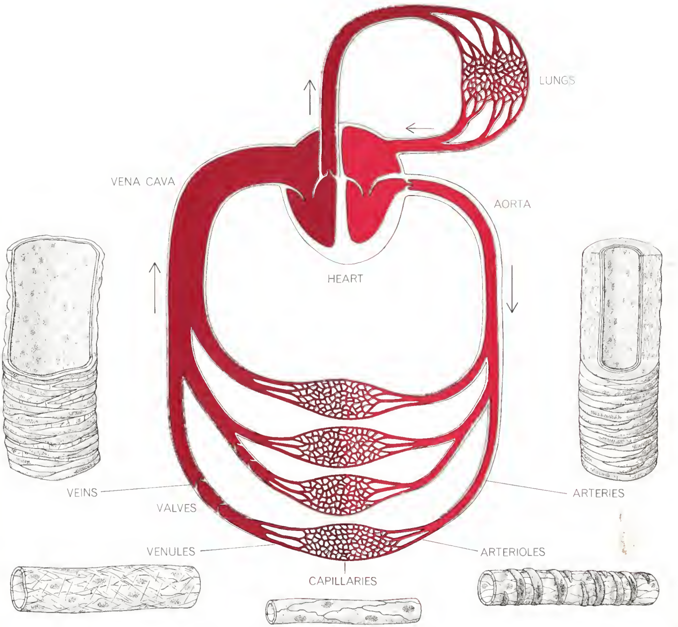
The next line of investigation was therefore to establish whether or not the veins constrict actively in response to various stimuli, and if so how. It had long been known that changes in the tone, or degree of stiffness, of the arterial vessels occur in response to certain stimuli and that these changes exert a powerful and immediate influence on blood pressure and the well-being of the organism. Changes of tone in the veins were much less obvious, so that new methods had to be developed to measure them under various physiological conditions in human beings. This has been done over the past 10 years or so by several groups of workers, including those groups with which I have been associated at the Boston University School of Medicine, the Medical College of Georgia and the University of Virginia Medical School. It is now established that the veins constrict actively, not only to preserve blood pressure in the highly distensible venous system but also to shift blood from the periphery toward the central circulation as required. The veins, in other words, comprise the reservoir of the circulatory system.

The successive components of the circulatory system can be described in terms of their characteristics as elements in a fluid-filled dynamic system. The heart is a pump with a power plant and valves that discharge oxygenated blood at a rate of flow of four quarts a minute. The arteries, which receive this blood at high pressure and velocity and conduct it throughout the body, are thickly walled with elastic fibrous tissue and a wrapping of muscle cells. The arterial tree terminates in short, narrow, muscular vessels called arterioles, from which the blood enters the capillary bed: a pervasive network of microscopic vessels whose tenuous walls act as a membrane across which nutrient and waste substances diffuse into and out of the tissues. From the capillaries the blood, now depleted of oxygen and burdened with waste products, moving more slowly and under low pressure, enters small vessels called venules and then the veins. These are generally larger and less thickly walled than comparable arteries; the layer of smooth muscle along their entire length is much thinner than that of the arteries, but then it has much lower pressures to cope with.

The entire vascular system, including the heart, is closely regulated by nerve impulses from the brain and spinal cord as well as by the intrinsic responsiveness of the vascular system itself. Nerve impulses reach the blood vessels and heart by way of the autonomic nervous system. The major source of nerve impulses to the blood vessels is in the sympathetic ganglia, collections of nerve cells that control the sympathetic nerve fibers. The impulses ultimately result in the release of the hormone noradrenalin (also called norepinephrine) at the nerve endings on smooth muscle in the walls of the arteries and veins and in the heart.

An important concept of nerve function is the receptor theory, first proposed by Raymond P. Ahlquist of the Medical College of Georgia and later confirmed as an explanation of nerve and muscle function in the vascular system. It holds that small protein receptor complexes on the walls of smooth muscle cells have characteristics that determine the response the cell will make when the receptor is stimulated by a suitable substance. When noradrenalin is released by the nerve ending in the vicinity of the receptor, stimulation of an "alpha" receptor results in contraction and therefore in blood-vessel constriction, whereas stimulation of a "beta" receptor results in relaxation and therefore in dilatation of the vessel.

John W. Eckstein and his group at the University of Iowa College of Medicine found that arteries contain both alpha and beta receptors, so that certain stimuli result in the dilatation of arteries and other stimuli in their constriction. The preponderant receptor effect of noradrenalin is alpha stimulation (although some beta stimulation also occurs), and so the net effect of noradrenalin on arteries is constriction. In veins, on the other hand, only alpha receptors are present, so that sympathetic nerve stimulation results only in constriction. As the various responses of veins are described later in this article, it will be noted that an increase in tone of the smooth muscle—a constriction of the vessels—is the usual and expected response



	VOLUME (CUBIC CENTIMETERS)	VELOCITY (CENTIMETERS PER SECOND)	PRESSURE (MILLIMETERS OF MERCURY)
AORTA	100	40	100
ARTERIES	325	40 – 10	100 – 40
ARTERIOLES	50	10 – .1	40 – 25
CAPILLARIES	250	LESS THAN .1	25 – 12
VENULES	300	LESS THAN .3	12 – 8
VEINS	2,200	.3 – 5	10 – 5
VENA CAVA	300	5 – 20	2

CIRCULATION is diagrammed schematically as a hydrodynamic system in which blood is forced into the arteries at high pressure by the heart and maintained at high pressure by the resistance effect of the arterioles, which supply the capillary bed that permeates all the tissues. Then, at low pressure, the blood enters the venules and finally the veins, many of which contain valves that keep the blood flowing toward the heart. The chart gives the total volume of all the vessels of each kind in man (note the great aggregate volume of the veins) and average values for the velocity and pressure in each kind of vessel. As shown by the drawings of segments of vessels, a single layer of endothelial cells lines the entire system, surrounded by fibrous tissue except in the case of the capillaries and by smooth-muscle cells in the case of arteries, arterioles and veins. The vessels are not drawn to scale.

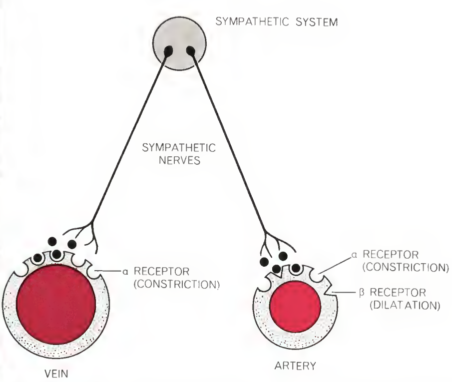
of the veins, whereas arteries may dilate or constrict. One reason for this difference in the pattern of response of these two systems is the difference in receptor makeup. (In addition certain arteries have vasodilator nerves that apparently function differently from the sympathetic constrictor nerves.)

The nervous system functions so as to cause the heart to increase or decrease its pumping action in order to maintain the flow of blood needed by the entire body. The arterial side of the circulation tends to respond to the need for flow to specialized tissues by maintaining arterial pressure. (For example, the arterial circulation to the brain tends to remain open while the circulation to less immediately essential parts of the body closes down during stressful circumstances.) On the venous side of the circulation nervous impulses impinge on the veins so as to maintain enough pressure and volume of blood in the central veins to form an adequate reservoir of blood for the heart to pump back into the lungs and ultimately into the arterial system.

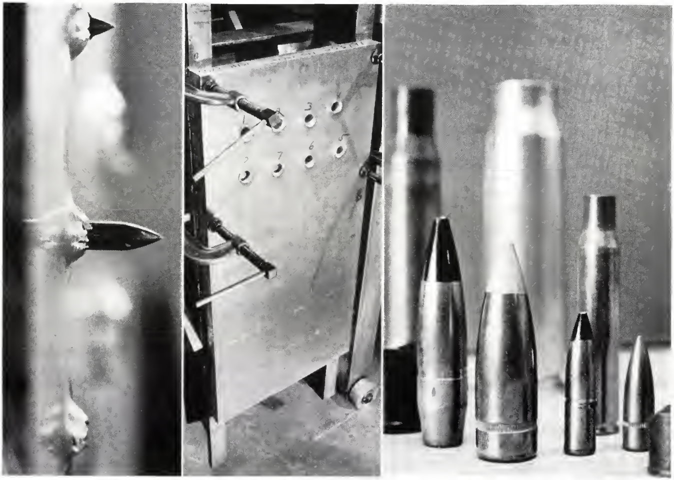
If we were to understand the functioning of the veins as an active reservoir, we needed to learn how they constrict and dilate, in health and disease, in response to various environmental conditions and other stimuli. More specifically, we needed data on the distensibility of the veins, which would indicate the degree of contraction of the muscles controlling the walls. The distensibility of any hollow organ (or a similar inorganic element) is described by the way in which its volume varies with the pressure of the fluid in it.

There are standard methods of measuring changes in volume and pressure in veins. The volume is recorded by measuring, with the instrument called a plethysmograph, changes in the size of a patient's arm or leg. This is possible because so much of the blood in an extremity is contained in the veins, and because the arteries and capillaries change their volume relatively little; fluctuations in the volume of the extremity can therefore be ascribed almost completely to changes in the volume of the veins. The extremity (the forearm in most of our experiments) is placed in an airtight, watertight box that is partly filled with water. Any change in the volume of the forearm causes a proportionate rise in the water level, displacing air from the box into a measuring device, such as a simple bellows, that operates a recording pen [*see top illustration on page 91*].

There are several ways to measure pressure within a vein, but the most



SYMPATHETIC NERVES are one source of control of muscle in blood-vessel walls. According to one theory, noradrenalin released by the nerve endings affects "alpha" receptors, causing muscle contraction, or "beta" receptors, causing relaxation. Arteries have both receptors, veins only alpha receptors, and so sympathetic activity always constricts veins.



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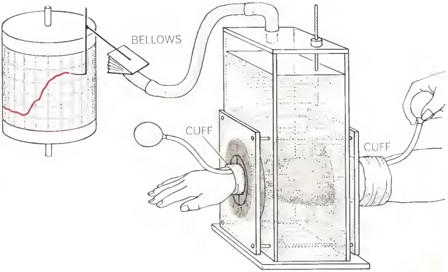
graphic is to introduce into the vein a flexible tube attached to a glass column filled with a salt solution. The height of the solution above the tip of the tube is a measure of the excess of the local venous blood pressure over atmospheric pressure.

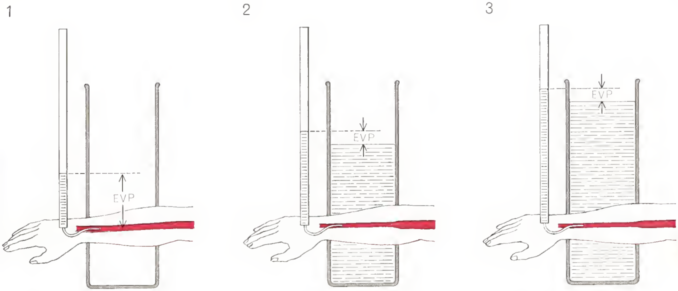
Clearly the mere measurement of volume and pressure is a simple affair. The problem is that in order to get reproducible pressure-volume curves and to compare results in different people under various conditions, one must start with a low and constant pressure and volume as a base line. Consider the problem of comparing the distensibility of a new and an old toy balloon. The distensibility of the new one is less than that of the old one; you have to blow harder to inflate it. When both of the balloons are inflated to the same pressure, say 30 millimeters of mercury, the volume of the old one is three times as great as the volume of the new one. That is a quantitative statement of the difference in distensibility of the two balloons and is valid because they began from the same base line: they had the same zero pressure and about the same low volume when they were deflated.



PLETHYSMOGRAPH records changes in forearm volume, thus measuring changes in the volume of the veins. The subject's arm is placed inside a rubber sleeve that forms a watertight seal with the sides of the plastic plethysmograph case. The pressure inside the veins is increased by inflating the pressure cuff (*right*), obstructing the flow of blood toward the heart; second cuff (*left*) temporarily cuts off circulation to the hand. Any increase in arm volume raises the water level, displacing air to operate the bellows and recording pen.

To accomplish the same result in the case of the veins we add water to the plethysmograph. This raises the venous pressure somewhat but, more important for our purpose, it reduces the "effective" venous pressure—the difference between the pressure within the vein and the pressure surrounding it—to less than a millimeter of mercury. Adding more water to the plethysmograph raises the venous pressure but does not change the effective pressure [*see illustration below*]. In other words, as long as the water pressure in the plethysmograph exceeds the normal local venous blood pressure, the effective venous pressure—the pressure that actually tends to distend the vein—remains constant. The veins, like deflated balloons, are therefore in a state of low constant pressure and volume regardless of the tone of their walls.

The next step is to increase the effective pressure as one does by blowing up a balloon. This is done by inflating a blood-pressure cuff on the upper arm and thereby obstructing the flow of blood toward the heart. We inflate the cuff until the arm volume increases just a bit, showing that the cuff pressure barely exceeds the local venous blood pressure. Beyond this point, which we

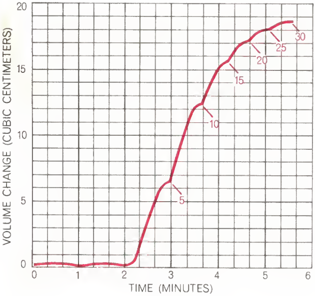


EFFECTIVE PRESSURE, the difference between the pressure inside and the pressure outside the veins, must be brought to a low, constant value for experiments on venous volume. This is done by adding water to the plethysmograph. In an empty plethysmograph the effective venous pressure (*EVP*) is equal to the blood pressure (*1*). If water is added, the pressure in the vein rises but the effective pressure becomes very small (*2*). More water further increases the internal pressure, but the effective pressure remains small (*3*).

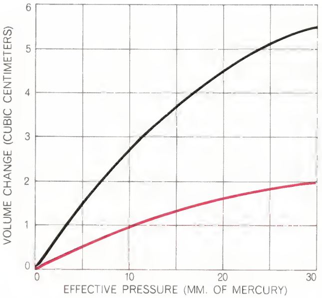
call an effective pressure of zero, any increment in cuff pressure causes an equal rise in effective venous pressure. Increasing the cuff pressure in five-millimeter-of-mercury increments, we note the change in volume recorded by the plethysmograph [*see illustration at upper left below*]. When these data are plotted, they yield the pressure-volume curve for the veins being studied [*see illustration at upper right below*].

The experiment can then be repeated under different conditions, in the presence of the hormone adrenalin, for example. Adrenalin (or epinephrine) is secreted by the adrenal gland and can also be synthesized. Whether it enters the bloodstream from the gland or is administered as a drug, it causes the arterioles to dilate but causes the veins to contract. (This is one of the cases in which the veins and the arterioles have opposite reactions to the same stimulus.) If we administer adrenalin to a subject, the muscle in the vein walls constricts and the veins become less distensible; the distensibility (or the change in volume at a pressure of 30 millimeters of mercury) is two cubic centimeters in the presence of adrenalin compared with 5.5 cubic centimeters under normal conditions.

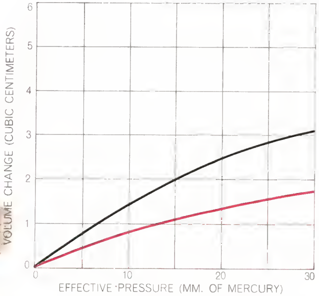
One of the important functions of the circulation is to help maintain a constant body temperature, and we therefore studied the effect of a change in temperature on the distensibility of the veins. At a room temperature of 83 degrees Fahrenheit a lightly clothed male,



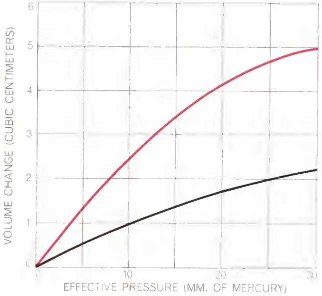
CHANGE IN FOREARM VOLUME as the effective venous pressure is raised is shown by a plethysmograph tracing. The effective pressure, from the base line to 30 millimeters of mercury, is shown by the numbers along the curve. The change in volume with each five-millimeter increment becomes less as the pressure rises.



DATA FROM TRACING are plotted to yield a pressure-volume curve, with the volume changes corrected for the size of the subject's arm. Here the curve for a healthy subject under standard conditions (*black*) is compared with the curve obtained while he was being given adrenalin, which constricts the veins (*color*).



PRESSURE-VOLUME CURVES for a patient with heart failure show how the distensibility of the veins is reduced when the patient is at rest (*black*) and further reduced during exercise (*color*).

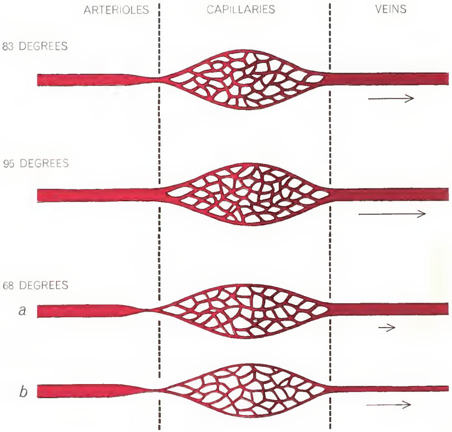


HEART-FAILURE PATIENT, exercising, has constricted veins (*black*). The administration of a drug that blocks the action of the sympathetic nervous system abolishes the venous response (*color*).

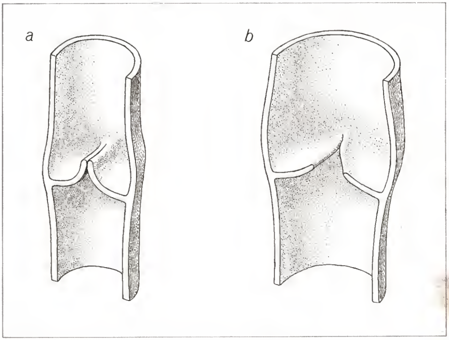
lying down, is in approximate thermal equilibrium with his surroundings. In such an environment the venous distensibility averaged four cubic centimeters. When the environment was warmed to 95 degrees, the subject's venous distensibility remained the same; nevertheless, calculations (based on the rate of rise of the plethysmograph tracing) showed that the volume of venous blood flowing through the forearm increased. What happened was that the arterioles had dilated, allowing more blood to flow. Since the tone of the veins remained unchanged, the velocity of the blood in the veins increased. Then, when the temperature of the room was reduced to 68 degrees, the arterioles constricted almost at once; the blood flow diminished and the veins constricted 10 to 15 minutes later, thereby restoring blood velocity in the veins to about the normal level.

If the veins of the arm are considered as radiators, then the conservation of heat in cold weather could best be accomplished if a minimal amount of blood flowed through them as rapidly as possible. That is what happened in the cold experimental situation. The removal of heat from the body in hot weather, on the other hand, could best be accomplished by a large quantity of blood exposed near the surface at a low velocity. Yet these conditions were not met in the warm experimental situation. The reason is that a certain pressure must be maintained in the veins in order to fulfill the system's functions as a reservoir, and this could not be done if the veins dilated enough to reduce the velocity.

One of the major physiological problems for man, the erect animal, is maintaining blood flow to all parts of the body. When a man stands up, the hydrostatic pressure in his leg veins approaches 100 millimeters of mercury; a large volume of blood tends to settle in the distensible vessels of the lower legs. This pooling of blood is counteracted, first of all, by simple flap valves in the veins, which act to prevent the return flow of blood moving upward; they tend to hold the blood in a series of short, low-pressure columns. We have found that a second important mechanism counteracts pooling: a generalized constriction of the veins, not only in the legs but also elsewhere in the body. We demonstrated this effect by measuring venous distensibility in the forearm of a patient wearing inflatable legging-like pressure stockings. When the stockings were inflated, preventing the pooling of blood, the forearm venous distensibility in a number of subjects averaged 3.8 cubic centimeters; 15



TEMPERATURE CHANGES prompt a venous response. At a room temperature of 83 degrees Fahrenheit arteriole resistance and venous volume are normal. At a temperature of 95 degrees the arterioles dilate but the veins do not, and so the blood velocity (*arrow*) in the veins increases. At 68 degrees the arterioles constrict and reduce blood flow, thus reducing venous velocity (*a*); then the veins constrict and restore the velocity to about normal (*b*).



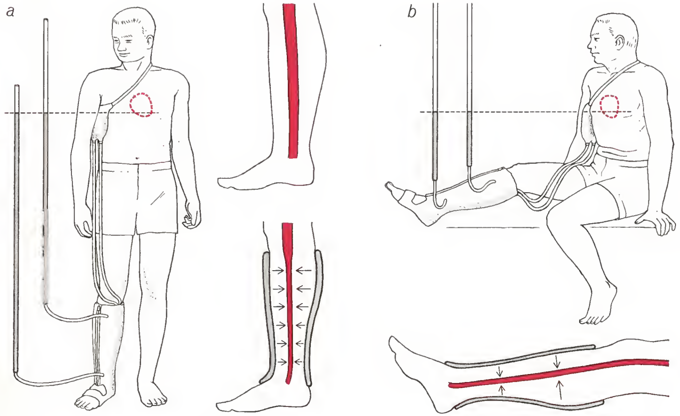
VALVE of a normal vein is composed of leaflets whose free edges meet intermittently to keep blood from flowing backward (*a*). If the valve functions badly, either because it has been damaged or because the vein walls are distended, blood pools in the vein, dilating it and further interfering with normal valve function. The result is a varicose vein (*b*).

minutes after the pressure was released, allowing blood to pool in the legs, distensibility in the arm averaged 2.6 cubic centimeters. In other words, although there was no change in the position of the forearm, the forearm veins constricted when blood pooled in the legs. This response has the ultimate effect of helping to maintain the pressure in the venous system and in particular near the heart. If this pressure is too low, there is inadequate blood flow into the heart and inadequate cardiac output; reduced blood flow to the brain often causes fainting, as in the case of a soldier standing too long at attention.

When a person exercises, the tissues require an additional supply of blood. The heart rate increases to meet this need, but the heart may be limited in its ability to respond if not enough blood is being returned to it by the veins. An experiment that David E. Bass and I performed at the U.S. Army Natick Laboratories in Massachusetts showed how the veins respond during exercise. The distensibility of veins in the forearm was measured in subjects walking a treadmill. The veins did constrict, showing a definite shift of blood away from the arm toward the heart to facilitate increased cardiac output. When the measurements were made at an elevated temperature, soldiers who were not conditioned to the heat showed evidence of inadequate cardiac output and specifically of inadequate venous response. Exercise for several days in the heat improved their responses, suggesting that the veins play a role in acclimatization to heat.

If the heart is subjected to some handicap that impairs its ability to function as a pump, such as high blood pressure, coronary artery disease or damage to the heart valves by rheumatic fever, then the condition known as heart failure may result. Some of the symptoms of heart failure are directly due to the fact that the heart is not pumping enough blood. Other symptoms, however, are caused by compensatory responses by the body to the lack of adequate blood flow, and one of the most interesting of these is a venous response. The normal heart is able to meet the total blood-flow needs of the body, even during mild exercise, without constriction of the veins. When the heart is handicapped, however, the veins are constricted even at rest. This chronic venous constriction, in association with the greater than normal total blood volume characteristic of heart failure, causes high pressure in the veins and capillaries, forcing large quantities of fluid through the thin capillary walls into the tissues. The resulting dropsy, or edema, is a common symptom in heart failure. Constriction of the veins in heart failure is evident in a patient at rest and is accentuated during exercise [*see illustration at lower left on page* 92]. The constriction of the veins in heart failure is induced by the autonomic nervous system. If a drug known to block sympathetic action is administered, the response is abolished, even during exercise [*see illustration at lower right on page* 92].

What the tissues lack both in heart failure and during vigorous exercise is enough oxygen. We wondered if the veins would respond to the relative lack of oxygen at high altitudes, and in collaboration with Sujoy B. Roy of the All India Institute of Medical Sciences we carried a plethysmograph into the Himalayas last summer. We found that when a man is exposed to an altitude of more than 10,000 feet, the responses of the



HYDROSTATIC STOCKING exerts a pressure that varies with the blood pressure in the leg. When the patient is standing, the pressure at the ankle (for a six-foot patient) would be about 100 millimeters of mercury (*a*). Without the stocking this would distend the vein (*top*); water pressure in the stocking keeps the vein from dilating (*bottom*). When the patient sits, the venous pressure at the ankle is about 50 millimeters (*b*); the stocking pressure also goes down. The stocking is used to treat ulcers from varicose veins.

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veins simulate those of the heart-failure patient in many respects.

When a person has high blood pressure that cannot be related to a cause such as kidney trouble, he is said to be suffering from essential hypertension. Although the origin of this condition is not known, the basic mechanical problem is clearly a constriction of the arterioles. Usually, as I have indicated, the arterioles and veins constrict together. It was therefore surprising to find, when we examined patients with essential hypertension, that their veins were not constricted. Other experiments suggest that the venous response may even be depressed in such patients. The importance of this finding is that it may narrow the field of possible causes of essential hypertension. For example, one suspected cause—increased activity of the autonomic nervous system—seems to be ruled out because it would almost surely have similar effects on both the veins and the arteries.

When blood flows too slowly, it has a tendency to clot. Clots that form in veins (thrombophlebitis) can break off and travel to the lungs, causing a pulmonary embolism, or stay in place and obstruct blood flow so badly as to cause serious edema. Thrombophlebitis can also damage the valves in a vein and is therefore one cause of varicose veins, a condition in which lack of valve function causes the blood to pool in the leg veins, which become chronically dilated. Varicose veins can arise from any injury to the valves or from the congenital absence of valves, but this is far from explaining the large number of cases. In 1966 we discovered that the venous distensibility is high in the forearm of patients who have varicose veins in the leg. Also in 1966, S. M. Zoster of the McGill University Faculty of Medicine, using different methods, found the same thing. This suggests that certain people inherit a venous disability that makes for lack of tone in the leg veins. When such a person stands up, abnormal dilatation of the veins keeps the valves from functioning properly, further dilating the vessels and leading to varicose veins.

Pregnant women have a predisposition to thrombophlebitis and to varicose veins, and some fatal cases of pulmonary embolism from thrombophlebitis have been ascribed to oral contraceptive drugs. We therefore measured venous distensibility in pregnant women and in women receiving oral contraceptives. In both cases we found that there was a generalized loss of venous tone compared with a control group. This may well explain the dilatation associated with poor valve function in varicose veins and with low velocity of blood flow in thrombophlebitis.

Usually varicose veins are superficial vessels that are not essential to the circulation; they can be tied off and removed by surgery. When a number of deep veins are involved, however, this is not possible. The constant high pressure of the pooled blood, unrelieved by valve action, can cause extreme edema that breaks down tissue and forms painful ulcers. Since dilatation of the vein wall depends on the difference between the pressure inside and the pressure outside the vein, the logical approach to therapy of advanced varicose veins would be to equalize those pressures. This would reduce the effective pressure to near zero and presumably force fluid out of the tissues into the blood vessels. In addition, by bringing the valve leaflets closer together, it would enable the valves to function better. The trouble is that an external pressure high enough to counterbalance venous pressure when the patient was standing would be so high as to cut off all circulation in the legs when he sat down.

After a series of experiments we devised a way to exert just the right amount of pressure on the veins of the leg regardless of the patient's posture: a hydrostatic pressure stocking, in which the pressure would be supplied by a reservoir of water at about the level of the patient's heart. John E. Flagg of the David Clark Company designed the stocking, which is attached by two tubes to a water bag carried under the patient's arm. Any point on the surface of the patient's leg is therefore constantly subjected to a pressure proportional to the vertical difference between that point and the level of the heart. The hydrostatic stocking has since proved beneficial to a number of patients suffering from ulcers due to varicose veins.

The stocking is one example of a practical therapy for malfunction of the veins that has been derived from experimental studies of normal vein function. As for our theoretical findings, I have a feeling that the most significant aspect may be the discovery of instances in which the veins constrict or dilate in a manner diametrically different from other components of the circulation. By pursuing these instances of apparently incongruous venous response we should be able to isolate mechanisms that combine to produce the complex responses of the vascular system in health and disease.

Freeing Coatings for Examination

Sophisticated electrolytic techniques separate metallic coatings from base steel for closer study. The result is a better understanding of coating characteristics and product applications.

by Samuel M. Purdy, Research Supervisor

Enormous amounts of steel are today being produced with metallic coatings. The Youngstown Sheet and Tube Company alone makes 700,000 tons of it each year. Most of it goes into sheet steel, which amounts to approximately 100,000,000 square feet of coated steel, not counting steel used in electroplating.

Coated steel has many uses. A common example is the so-called tin can, actually made of tin coated steel. Galvanized steel is familiar as roofing and siding for farm and industrial buildings, such as the Quonset hut. The list of uses is almost endless.

Newly created conditions demand new varieties of coated steels. For example, the high price of tin and the political instability in tin-producing countries have led to a search for safe substitutes for tin plate in food containers. Cost conscious users of galvanized steel have helped motivate the development of varieties which don't need primer coats in painting.

New technological improvements such as vapor deposition suggest new methods of applying coatings to metals – coatings heretofore impossible. A thin film of Al, Ti or stainless steel on steel now seems possible. Some of the coatings now foreseen may be extraordinarily thin.

These new coatings and processes require new techniques for characterization of coatings. What will work for tin plate will not work for vapor deposited Al or stainless steel. At the same time, the effort to improve conventional products requires a closer look at today's coatings. And that look must be made from a different viewpoint. That is, while properties like color, reflectance and corrosion resistance have been readily observed on the coated steel itself, newer studies show that more information can be obtained after the coating has been separated from the steel. This is especially true of thin films made by electro-deposition, or by the new vapor deposition techniques.

Properties to be seen through deeper scrutiny include chemical composition, grain size, micro structure, etc. But, properties that make a good film, such as tight adherence, make separation difficult.

Because the coating can't be peeled from the steel, unless the coating was faulty to begin with, and since chemically dissolving the coating defeats the purpose, the steel must be taken away from the coating. This can be done by taking advantage of chemical differences between coating and steel.

One such difference is the phenomenon called "passivation." If a metal specimen is the anode in an electrolytic cell, its corrosion rate is proportional to the current flowing through the cell. Most metals corrode faster as the voltage is increased because more current flows.

Some metals, like Fe and Cr, don't behave this way. At first, as voltage increases, current increases. But at some critical voltage, the current through the cell drops suddenly to a low value. The metal becomes passive and does not corrode rapidly.

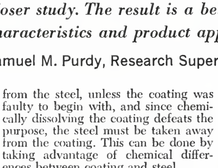
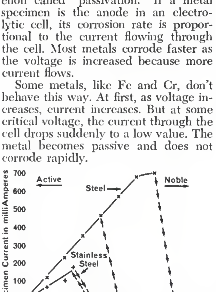


Fig. 1 Anodic Corrosion Behavior of Iron and Stainless Steel



Plots of current vs. specimen potential in 1N H_2SO_4 for steel and stainless steel are shown in the accompanying graph. Specimen potential is measured on the anode, showing accurately what is happening there without becoming entangled with cathode reactions. Steel corrodes actively, i.e., there is a large current flow at potentials up to + .2V. But above this value, up to 1.0V, there is an unstable region in which the steel becomes passive. The rate of passivation depends on how far above + .2V the specimen potential is set. The stainless steel coating shows a similar behavior, but with a different set of values well below those of steel.

Now we have the principle for a technique to separate steel from a stainless steel coating. The specimen is made the anode in an electrolytic cell containing 1N H_2SO_4. When the anode potential is set between − .1V and + .3V, steel corrodes and stainless steel becomes passive and is not attacked.

Interestingly, the technique reveals poor adhesion. Poor films flaked off readily across the specimen's face when the stainless face was electrolyzed, indicating a relatively greater amount of exposed Fe in the poor coating and implying that the coating was porous. Good specimens did not flake off, but came off in sheets. Electron microscopic examination showed that good films were free of observable porosity up to 100,000 × and that poor films had numerous pores less than ½ micron (20 micro inches) in diameter.

Coatings produced by vacuum evaporation appear extremely fine grained. Grain size for good coatings ran from 1400 down to 800 Å mean diameter and down to 500 Å in one poor one.

The technique has been extended to extremely thin (up to 1000 Å thick) coatings of electroplated Cr. The Cr plates were extremely fine grained, estimated at 100Å mean diameter or less. Diffraction patterns showed a preferred orientation in that the (110) plane was parallel to the substrate surface but that the direction varied from place to place. The Cr plate showed no obvious pores up to 100,000 ×.

The work in the development of these techniques has been only a small part of the constant research at Youngstown. If you believe Youngstown can help you, call at your convenience. Or, write Department 251D8.

Gas chromatography...

can help develop a better material, improve our physical well-being . . . and catch a hit-run killer.

A motorcyclist was killed by a hit-run driver, a suspect car located. Police found traces of grey and red plastic on its bumper. The problem: how to establish whether the plastic on the automobile came from the motorcycle. Gas chromatography was used to analyze the scrapings from the suspect car and the wrecked motorcycle. The chromatograms, showing exact chemical composition of the plastics, provided comparable chemical "fingerprints" of the two samples. They matched... and these "fingerprints" were used as admissible evidence in court to establish the car's role in the accident.

How it works: Gas chromatography (GC) is a process whereby a vaporized material is separated into its constituent compounds as it passes through an adsorptive column. The output of sensitive detectors at the end of the column provides a graph, or chromatogram, showing both the identity and exact quantity of the separated compounds. This efficient analytical tool, combining quantitative analysis with qualitative identification, makes a positive contribution to our lives today... from the purity of the water we drink to the ability of our automobile to stop quickly and safely.

Health-guard: By developing the high-efficiency gas chromatograph, Hewlett-Packard made practical the detection of harmful pesticide residues in foodstuffs ranging from human milk to raspberry preserves. Hewlett-Packard GC instrumentation can detect the presence of as little as a picogram (10^{-12} gram) of a pesticide. Because of the toxicity of these chemicals, this 1000-time improvement in sensitivity is of significant importance to pesticide manufacturers, biomedical researchers, and government agencies concerned with public health.

GC in laboratory and factory: In industrial research, GC is an important tool for improving both product quality and manufacturing economy. As an example, brake lining material, by design highly resistant to decomposition, was analyzed by combining two HP-developed techniques: pyrolysis GC (where the sample is burned to obtain the test gas) and temperature-programmed GC (allowing separation from a mixture of compounds with widely separated boiling points). Several brake lining formulations were analyzed; their chromatograms showed a direct correlation between the presence of a new compound formed during curing and the actual stopping-ability of the linings. A new brake lining formulation was devised that improved performance with less cost. GC became the quality control specification test for this manufacturer to assure consistency of formulation and, thus, the stopping-ability of the brake lining.

Making pure chemicals: Beyond the analysis of small samples, gas chromatography has proved to be a uniquely efficient technique for producing useful liter-quantities of highly pure chemicals. By increasing the volume capacity of "preparative" GC more than 100 times, Hewlett-Packard has added further to the practicability of preparative gas chromatography for industrial use.

Other Hewlett-Packard analytical instruments:
Vapor pressure osmometers, $2800.
Membrane osmometers, $4225 to $5550.
CHN analyzers, $6000.
Microwave spectrometers, $40,000 to $60,000.
Gas chromatographs, $1095 to $5400.

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Software behind the hardware: Analytical instruments are among the more than 1500 Hewlett-Packard instruments for chemical, electronic and medical applications. From Hewlett-Packard sales and service offices our engineers and specialists provide customers with help in application, installation and maintenance of these instruments. Through these 107 offices extensive customer training programs and a continuing flow of helpful information are available—on a local basis—to meet the immediate and long-term needs of those whose progress depends on measurement.

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The Circulation of the Sun's Atmosphere

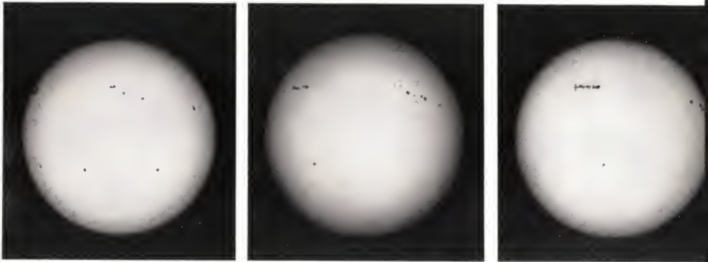
A new hypothesis may explain how the sun can rotate faster at its equator than it does elsewhere. Analysis of sunspot movements has provided a clue to this 100-year-old mystery

by Victor P. Starr and Peter A. Gilman

When Galileo observed that dark spots frequently travel across the face of the sun, he concluded correctly that the sun rotates. Closer observation subsequently showed that the sun rotates perhaps 20 percent faster at its equator than it does near its poles. Since the sun is not a rigid body but a ball of luminous gas, such differences in its rate of rotation may not seem too surprising until one tries to account for them. Then one finds that a satisfactory explanation is not so easy to invent. The task would be simplified if there were some direct way to follow large-scale motions of gas in the sun's atmosphere, but this too is difficult. In the past few years, however, interesting clues to the general circulation of the solar atmosphere have been obtained by statistical analysis of the motions of sunspots. Additional clues have been provided by new investigations of the sun's magnetic field. We have drawn on studies of both kinds to construct a hypothesis that satisfactorily accounts, we believe, for the sun's nonuniform rate of rotation. The hypothesis is similar to the one that accounts for currents such as the high-speed flow of air in our own atmosphere known as the jet stream.

The generations of astronomers who followed Galileo spent countless hours examining the activity of the sun, and the study continues with ever more sophisticated instruments. It has always been easier to record and describe solar events than to provide theoretical explanations for them. This is hardly surprising when one considers that the sun represents the interaction of matter and energy on a scale that cannot be even remotely approached in the laboratory. The sun is 865,000 miles in diameter—more than three times the distance from the earth to the moon—and contains more than 99.9 percent of all the matter in the solar system.

Although we speak of the surface of the sun, this surface is not a surface in the usual sense. The limb, or visible edge, of the sun is the dividing line between two layers of the solar atmosphere. The layer extending inward from the limb is called the photosphere. Its thickness is about 400 kilometers, and it is the direct source of nearly all the sun's radiation into space. Estimates vary somewhat, but the temperature at the limb is some 4,500 degrees Kelvin (degrees centigrade above absolute zero), increasing to some 8,000 degrees K. at a depth of 400 kilometers. The layer extending outward from the limb is the chromosphere. Its thickness is now taken to be no more than 6,000 kilometers, through which the temperature increases from 4,500 degrees K. at the base to a million degrees K. at the top. Above



SUNSPOT MIGRATION provides the principal evidence that the sun rotates faster at its equator than it does toward its poles, a puzzling phenomenon known for about 100 years. This sequence of six photographs shows the migration of a large sunspot group over a 12-day period early last year, from its emergence on the east (left) limb in the northern hemisphere to its disappearance on the west limb. The dates of the sequence are February 21, 23, 25, 27, March 1 and 4. In the fifth picture the two spots seen in the small

the chromosphere is the corona, which reaches out to a distance equivalent to several solar radii and has a temperature exceeding a million degrees. The densities in the chromosphere and the corona are much lower than those in the photosphere. About 92 percent of the atoms in the photosphere are hydrogen, 8 percent are helium and less than .1 percent are heavier elements. Except in the layers of lowest temperature, these atoms have been stripped of one or more electrons and thus exist as positively charged ions.

The sun is observed primarily by recording its electromagnetic radiation, ranging through the entire spectrum from gamma rays to radio waves. With the advent of artificial satellites it has also been possible to measure the flux of material particles emitted by the sun. From the radiation measurements one can infer the local intensity, temperature, composition and state of ionization of the solar gas and also estimate the local magnetic fields and components of fluid velocity.

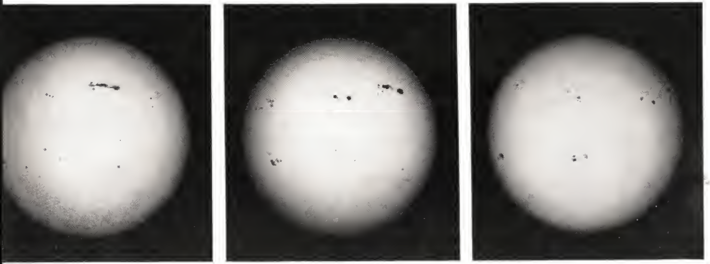
The magnetic fields are studied by analyzing lines in the spectrum, which are split into two or more closely spaced lines when the atoms that give rise to the lines are in a magnetic field; such split lines are named Zeeman lines after their discoverer Pieter Zeeman. Unless the field is precisely at right angles to the direction of the radiation, the spectral lines will also be circularly polarized in a sense that depends on the direction of the field. By determining how much the lines have been shifted and how they are polarized one can determine the strength of the magnetic field in our line of sight. The solar magnetograph, an instrument for measuring Zeeman shifts, was developed largely by Harold D. Babcock and his son Horace W. Babcock of the Mount Wilson and Palomar Observatories, whose solar observations cover a span of more than 50 years [see "The Magnetism of the Sun," by Horace W. Babcock; SCIENTIFIC AMERICAN, February, 1960].

Fluid velocities on the sun can be determined in two principal ways. One can examine spectral lines to see whether they are shifted to a shorter or a longer wavelength. A shortening indicates that the source of radiation has a component of motion toward the observer; a lengthening indicates that the source is receding. This is the well-known Doppler effect. Alternatively one can study the progressive movement of gross solar features, such as sunspots, for clues to the motion of the gas in which they are embedded. Both techniques have inherent difficulties. For example, it is not clear how well the movement of a sunspot represents the motion of the gas surrounding it. Nor can one determine with much precision to what level in the solar atmosphere a given set of observations pertains.

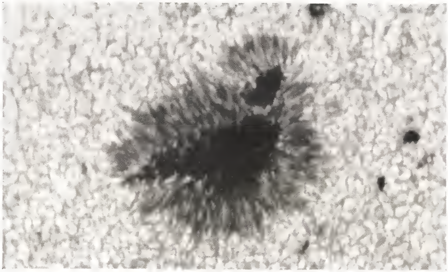
The ultimate source of the sun's radiation is of course nuclear energy released in the sun's inner core. Because the rate of this release is fairly steady, the flux of energy emitted by the sun as a whole is similarly steady. In regions of the surface, however, and over short periods of time, the radiation fluctuates in intensity and in distribution across the spectrum. These fluctuations range in duration from a few minutes to many months. They vary in horizontal scale from a few hundred kilometers (the limit of resolution with present instruments) up to a distance equal to the sun's radius. Most of the fluctuations are related to fluid motions on the same scale. Some are also linked to magnetic-field configurations of comparable dimensions.

The smallest and briefest of these disturbances take the form of the small-scale convection cells known as granules. The solar disk is covered rather uniformly with granules, which give the disk its mottled appearance in high-resolution photographs. Although the existence of the granules had been known for some time, pictures made in 1958 with the balloon-borne telescope of the Stratoscope program showed them in unprecedented detail [*see top illustration on next page*]. Martin Schwarzschild of Princeton University, who conceived and directed the project, found that the granules have an average diameter of about 700 kilometers and an average lifetime of about eight minutes. Mean temperature fluctuations across a granule are about 90 degrees K. The gas velocities, which indicate the vigor of convective motions in individual cells, are about .3 kilometer per second. There is little evidence so far that magnetic fields are associated with the temperature and velocity changes in the granules.

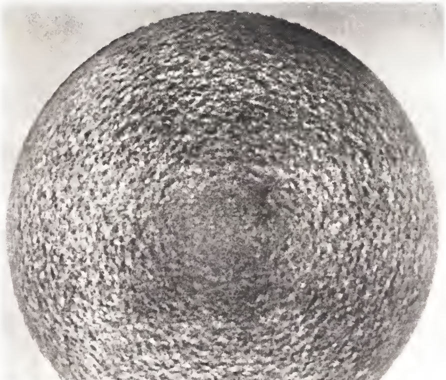
Recent studies indicate that larger and longer-lived convection cells are superposed on the granules; they are called supergranules. The motion associated with them shows up in Doppler shifts observed primarily near the limb of the sun. Near the center of the sun's disk their motions are apparently obscured



group centered on the north-south axis developed very rapidly in a 48-hour period between February 27 and March 1. Sunspots characteristically wax and wane in a nine-to-13-year cycle. The present solar cycle began in 1964 and will reach a maximum intensity in 1968 or 1969. Early in the cycle spots usually appear at around 40 degrees latitude; later they appear closer and closer to the equator. The photographs were made with a six-inch telescope at the solar observatory of the Aerospace Corporation near Los Angeles.



SUNSPOT SURROUNDED BY GRANULES is vividly depicted in this photograph made from a Stratoscope-program balloon. The granules are convection cells, a few hundred kilometers across, whose lifetime is about eight minutes. They are the smallest visible solar features. The diameter of the sunspot shown here is roughly that of the earth. Stratoscope program was conceived and directed by Martin Schwarzschild of Princeton University.



SUPERGRANULES, some 50 times larger in diameter than granules, can be inferred from photographs that register the Doppler shift in selected spectral lines. In this technique, devised by Robert B. Leighton and his co-workers at the California Institute of Technology, images are recorded at two nearly adjacent wavelengths, representing the red and blue "wings," or edges, of a particular line. These wings are either enhanced or decreased in intensity depending on whether the solar gas is moving toward or away from the observer. When the positive of one image is superposed on the negative of the second, the Doppler-shift contribution is enhanced, whereas density variations due simply to variations in intrinsic brightness cancel out to a uniform gray. In the "Doppler sum" photograph above the light areas represent motion of gas toward the observer and dark areas gas that is receding.

by the more intense activity of the granules; this has led observers to conclude that the larger motions are chiefly horizontal. John W. Evans of the Sacramento Peak Observatory, Robert B. Leighton of the California Institute of Technology and others have found that the supercells are some 30,000 kilometers in diameter and that their lifetime averages about 20 hours. There is evidence that the supergranules may be rising at the center and sinking at the edges at about a third of the rate observed in granules, or about a tenth of a kilometer per second. Horizontal outflow velocities, however, are about half a kilometer per second.

Like the granules, the supergranules seem to be spread rather uniformly over the sun's surface [*see bottom illustration at left*]; about 2,500 large cells are needed to cover the visible disk. Unlike the small granules, the supergranules seem to be bounded by fairly strong magnetic fields. On the whole the supergranules appear to be something quite different from the granules.

A number of other solar features are not uniformly distributed over the surface. Most of them appear to be associated in one way or another with the solar cycle, or sunspot cycle, which generally lasts between nine and 13 years. The most familiar of these cyclic phenomena is the sunspot itself. It is distinguished from the two kinds of granule by its lower temperature and strong vertical magnetic field. A typical sunspot is only 40 percent as bright as the surrounding area. The intensity of its magnetic field ranges up to 3,000 gauss, compared with background fields of between one and 100 gauss. Although the spot is cooler (and therefore darker) than its surroundings, it is not quiescent. It is commonly turbulent, and in it there is usually an outward flow of perhaps one kilometer per second. This flow is named the Evershed effect after its discoverer John Evershed.

Sunspots vary greatly in area. The smallest single spot, sometimes called a pore, is perhaps 1,500 kilometers in diameter, or about a millionth of the area of the solar disk; the largest can be several hundred times larger. A typical spot is about the size of a supergranule. Small spots may last only a day or so; larger ones may last a month or two.

Sunspots often appear in groups, and usually one or two spots are much larger than the others in the group. Practically all groups are divided into two regions of opposite magnetic polarity. Many groups have an elongated form, with the long axis nearly parallel to the sun's

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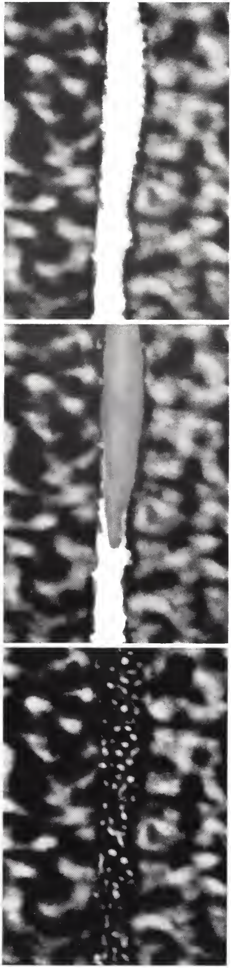
Do you really need vats of muriatic acid, pots of paste, jars of powder or cores of rosin to solder pieces of metal together? Plus time to heat each part and then to melt the solder? No. At Western Electric's Engineering Research Center we've discovered that if you force hot solder between cold metals held tightly together, they'll stick fast — without pickling, flux, or even much heat.

The pressure between parts and the flow of molten solder exclude corrosive gases. The molten solder itself raises temperatures quickly with little thermal shock. The injected melt both cleans and wets the surfaces. And, if necessary, a die mold gives precise shape and rapid cooling.



In these photomicrographs molten solder is forced between two copper wires spaced about 0.1 mil apart.

Actual joining times range from 1/10th to 1 second, far faster than hand-soldering. The small amount of energy required safeguards sensitive materials. Equipment is simple, inexpensive, and easy to maintain. Precision control is maintained even over wide latitudes of operation.

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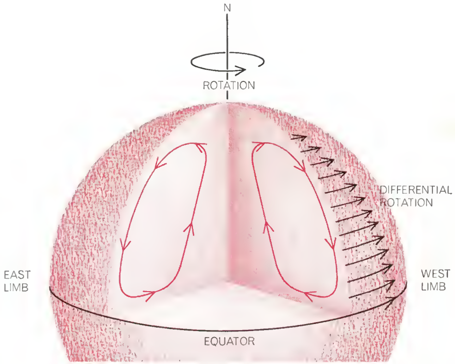
equator. The leading end (the end nearest the right edge, or west limb, of the disk) is almost always closer to the equator than the trailing end. As we shall see, this characteristic orientation may be related to the wave structure of the general circulation of the solar atmosphere. The major spot at the leading end of a group in one hemisphere almost invariably shows a magnetic polarity opposite to that of a similar spot in the other hemisphere.

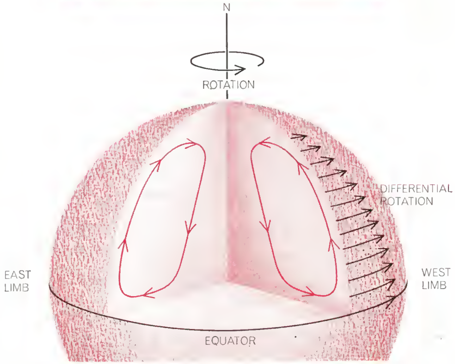
Well-developed sunspots generally occur in association with other magnetic and thermal structures, but these need not concern us here. Such structures include plages and faculae (bright blotchy or striated areas), filaments (twisted or looped prominences that often arch above the photosphere) and flares (short-lived eruptions of brightness).

At the beginning of a new sunspot cycle the first sunspot groups materialize near 40 degrees north and south of the solar equator. The spots populate two belts of latitude 15 to 20 degrees wide. As the cycle progresses the new spots tend to arise closer and closer to the equator. Near the end of the cycle the spots form within two or three degrees of the equator. Often a new cycle begins before the preceding one is completed. As measured by the number and total area of sunspots, spot activity increases rapidly after the start of a new cycle, reaching a peak in about three or four years. For example, the most recent cycle, which began in late 1964, should reach a peak in late 1968 or 1969. In such a period of intensification there is also an increase in the number of plages, filaments and flares.

In addition to the intense magnetic fields associated with sunspots, there are evidently weaker and more diffuse fields. These are identified as bipolar or unipolar magnetic regions, depending essentially on how large an area of single polarity or double polarity they contain. The boundaries of such regions are much larger than even the largest sunspot group, extending at times to an area covering a tenth of the solar disk.

These regions have been examined most intensively by V. Bumba of the Czechoslovak Academy of Sciences and Robert Howard of Mount Wilson and Palomar. They find that the diffuse magnetic fields are primarily vertical, with typical intensities in the larger regions of between one and 20 gauss. The number, intensity and area of these fields also seem to vary with the sunspot cycle. Typically the bipolar regions are concentrated below latitude 40 in each hemisphere. Regions of opposite polarity at about the same latitude are arranged in a somewhat regular way around a latitude circle, with six or so regions of each polarity present. Toward the poles from latitude 40 the fields are primarily of a single magnetic polarity. Satellite observations indicate that some features of these fields extend outward from the sun's surface, reaching perhaps as far as the earth. Both the unipolar and the bipolar magnetic regions are characteristically tilted in longitude and latitude; in the sun's northern hemisphere they slant from upper left (east) to lower right (west) and in the southern hemisphere





TWO SOLAR MECHANISMS proposed some years ago for maintaining the sun's nonuniform rotation depend on a large-scale meridional circulation that is symmetric about the solar axis. It is clear, however, that neither scheme can explain how angular momentum is continuously transported to the equatorial region. The first (*top*) would bring rings of gas from more slowly rotating latitudes (*short arrows*) to replace the faster rings (*long arrows*) near the equator. The second (*bottom*) would carry fast-moving rings away from the equatorial region, so that the rotation at higher latitudes would tend to become even more rapid.

they do the opposite [*see illustration below*].

Many observers have tried to measure large-scale temperature differences across the disk of the sun, particularly between the equator and the poles. So far it is not certain that such differences exist. If they do exist at observable levels, they are unlikely to be larger than a few tens of degrees centigrade; otherwise the existing observations would show better agreement. Although such temperature differences would amount to only about one part in 300, compared with the average surface temperature, they could have an important effect on the circulation of the solar atmosphere.

Considering these many kinds of solar phenomena, what conclusions can be drawn about large-scale motions on the sun? So far sunspots have provided the most useful clues. It was through the careful tracking of sunspots that Richard C. Carrington of Britain recognized a century ago that the sun rotates faster at its equator than near its poles. This difference in rotation is known technically as the equatorial acceleration. A typical rotation period is 25 days for the equator (about 14.5 degrees of longitude per day) and 27 or more days poleward of 35 degrees latitude (13.7 degrees of longitude or less per day). Ever since the discovery of the equatorial acceleration, solar observers and theoreticians have been perplexed about how it has been maintained, presumably over hundreds of millions of years. So far there has been no complete and generally accepted explanation, but we think our model represents significant progress.

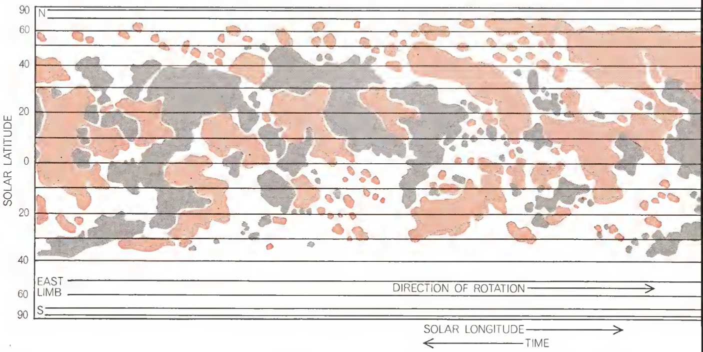
One can ask, of course, whether the equatorial acceleration needs to be "maintained" at all. In other words, if it somehow originated early in the sun's history, would it not simply continue? Indeed, some theoreticians once believed that no force would have been strong enough to destroy the equatorial acceleration in the sun's lifetime, but this view now has little support. For one thing, the solar cycle draws some of its energy from the differential rotation. This alone would probably reduce the sun to uniform rotation in a relatively short time.

If one accepts the idea that some physical process is needed to maintain the equatorial acceleration, one would like to find out what it is. All processes that dissipate energy, whether they are frictional or electromagnetic, will tend to equalize the velocities of rotation at all latitudes and depths. What is needed, therefore, is some process to oppose the dissipative ones—presumably a process involving large-scale systems of motion organized in a particular way.

The simplest motions that have been considered are closed circulations confined to planes cut through the sun's poles and symmetrical around the axis of rotation. It is difficult to see, however, how such motions would achieve the desired result. Consider a simple example. Assume that gas flows horizontally across the sun's surface from the region of the poles toward the equator, where it sinks and flows poleward again somewhere inside the sun, thus forming a closed loop [*see illustration on preceding page*]. Such circulation would carry material from a region of low angular momentum (the poles) to one of high angular momentum (the equator). Clearly it would be the opposite of what is desired.

Suppose the sense of circulation were reversed, so that the flow near the equator were upward from the interior, with a poleward motion along the surface and a sinking motion near the poles. The angular momentum needed at the equator might be brought up from the interior, where (hypothetically) the rotation might be faster than at the surface. The poleward flow on the surface, however, would tend to carry the equatorial fluid with high angular momentum to higher latitudes, imparting to those regions an even higher angular velocity than existed at the equator. This result is again the opposite of the one sought.

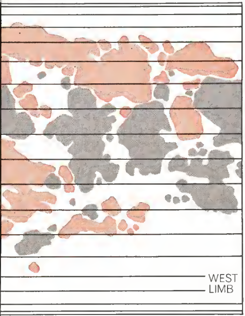
The point of this argument is that we should look to motions that are not sym-



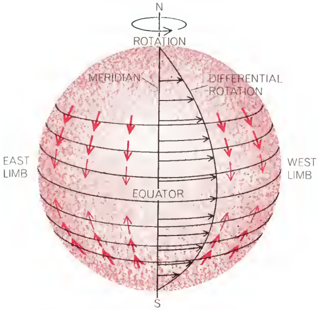
SOLAR MAGNETIC FIELDS are displayed for one rotation of the sun in August, 1959. The shaded areas represent line-of-sight magnetic fields with a strength of more than two gauss; gray areas are positive in polarity, colored areas are negative. Because these patterns tend to persist through successive rotations, the map can be regarded as an instantaneous picture of the distribution of large-scale magnetic fields. Between the equator and 40 degrees latitude the fields tend to alternate in polarity. Nearer the poles the fields are predominantly of one polarity. They also show a pronounced tilt from the poles toward the equator, suggesting that the equa-

metrical around the sun's axis of rotation. This was first suggested a few years ago by Fred Ward of the Air Force Cambridge Research Laboratories. Without appealing to any particular observed motions, we can decide what general properties they must have in order to maintain a maximum of angular velocity at the equator. Whatever else they may do, the motions must be capable of selectively transporting momentum in a preferred direction, from latitudes or levels (or both) where angular velocity is low to latitudes or levels where it is high. This can be accomplished by "Reynolds shear stresses" (named after Osborne Reynolds of Ireland, a 19th-century hydrodynamicist). As we shall see, these stresses arise when the fluid entering a given volume of space differs in some component of motion from the fluid leaving that volume. Since there are three mutually perpendicular components of motion, there can be three independent Reynolds shear stresses. A change in any one of the three components of motion is accompanied by a change in momentum transport. Momentum of a particular component will be added to a given volume only if more momentum of this type comes into the volume than leaves it. When this happens, there is said to be a convergence of momentum transport into the volume.

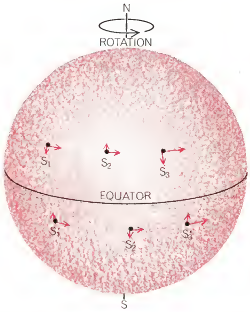
In the case of the sun, then, what is



tor's higher rate of rotation is dragging the fields to the right. The map is based on one by V. Bumba of the Czechoslovak Academy of Sciences and Robert Howard of the Mount Wilson and Palomar Observatories.



TRANSPORT OF ANGULAR MOMENTUM ON SUN must be in the direction needed to "fuel" the higher rate of rotation at the equator. This nonuniform rate of rotation, known as the equatorial acceleration, is represented by the horizontal arrows. The vertical arrows represent the transport of angular momentum in the solar atmosphere: at each latitude more momentum must enter from the direction of the poles than leaves in the direction of the equator.



CLUES TO MOMENTUM TRANSPORT can be found in sunspot movements. On the average spots moving fastest toward the right limb (S_3, S_3') are also moving fastest toward the equator. Those moving to the right more slowly are moving more slowly toward the equator (S_1, S_1') or toward the poles (S_2, S_2'). If the spots are being carried by large eddies of gas, the eddies must be transporting the momentum needed to maintain the equatorial acceleration.

needed is a convergence into equatorial regions of momentum of the same sense as the direction of rotation (that is, zonal momentum toward the right, or west, limb). This could be effected either by a net upward transport of zonal momentum from interior equatorial levels at a greater rate than at higher latitudes, or by an equatorward transport of zonal momentum horizontally across the surface. (A third possibility is downward transport of zonal momentum from levels above the photosphere, but this is unlikely to be significant because the density of gases falls so rapidly above the photosphere that little momentum could be transported.)

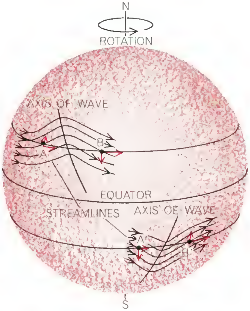
Is there any observational evidence for a horizontal transport of momentum toward the sun's equator? The answer is yes. The first such evidence was published about four years ago by Ward. His statistical analyses are now the most extensive ever made of the motion of sunspots and sunspot groups, using data from the Greenwich Observatory for seven sunspot cycles, extending back into the 19th century. In addition to calculating the mean longitudinal motion of spots, which is a direct measure of the differential rotation, Ward computed the mean latitudinal (that is, north-south) motions, the root-mean-square values for motions in both longitude and latitude, and the degree to which these motions vary together.

He found that the mean latitudinal motions were not statistically significant except close to the solar equator. His values for the root-mean-square motions were about .8 degree of longitude per day and .4 degree of latitude. The longitude value is about the same as the difference in the mean rotation rate between the equator and a latitude of 35 degrees. Taken together, these statistics seem to suggest that the difference in rotation toward the poles and toward the equator, at least insofar as it has been measured by sunspot motion, decreases smoothly with latitude only on the average over a period of time. At any particular time the flow is likely to be rather more complex, with horizontal "eddies" distorting the average motion. Since sunspots are being used to identify them, these eddies must have characteristic horizontal dimensions significantly larger than sunspots, dimensions probably comparable to those of the large-scale magnetic regions, which is to say around a few hundred thousand kilometers. If this is true, the eddies represent motions distinctly larger in horizontal scale but smaller in magnitude than the granules and supergranules.

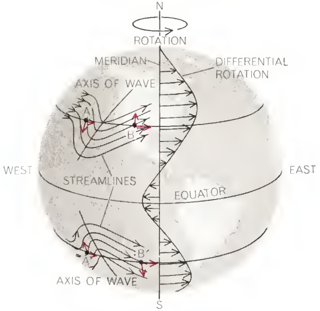
One cannot automatically assume, however, that sunspots completely reflect the motions of the surrounding gas. As we have noted, spots are continuously interacting with their surroundings, and therefore cannot be expected to be carried along exactly by the surrounding flow. The growth and decay of individual spots in a sunspot group can also lead to an apparent movement of the group's "center of gravity." Nonetheless, spectroscopic Doppler-shift measurements near the sun's limb yield values of mean rotation that agree fairly well with values derived from spot motions, and thus provide a partial check of Ward's calculations. To us it therefore seems most likely that a large fraction of the spot motions can safely be attributed to motions of the surrounding gas.

Ward's findings bear on the problem of the equatorial acceleration in the following manner. They show that the motions of sunspots and spot groups toward the sun's west limb (the direction of rotation) are positively correlated with their equatorward motion. This is true in each hemisphere and for each of seven successive solar cycles. If one accepts spot motions as being genuinely indicative of the motion of the surrounding gas, this positive correlation represents a transport of zonal momentum toward the equator in a band extending at least 40 degrees north and south of the equator. These findings result in a horizontal Reynolds shear stress of the appropriate sign.

Ward's figures show, furthermore, that the shear stress increases with latitude, so that momentum is indeed converging



HYPOTHETICAL SOLAR EDDIES, inferred from the study of sunspot movements, have instantaneous streamlines whose structure is commonly tilted in opposite directions on opposite sides of the equator. Thus the equatorward transport of momentum at B and B' is stronger than the poleward transport at A and A' because the angular momentum is greater in front of the wave than behind it. Eddies with closed circulations would be tilted in a similar way.



EDDIES IN EARTH'S ATMOSPHERE provide a model for solar eddies. The horizontal arrows show the annual mean wind velocities at an altitude of about 10 kilometers where they reach a maximum. The mechanism for transporting momentum into the regions of positive acceleration, one in each hemisphere, are eddies that usually have the tilted wave structure depicted here. The eddies transport momentum poleward from the tropical and subtropical zones.

into the equatorial regions from higher latitudes in each hemisphere. Thus the large horizontal eddies, which we identified with the root-mean-square velocities of the sunspots, have the crucially important function of maintaining the equatorial acceleration by transporting momentum to it. This property of the large eddies requires that they have a particular structure.

What structure are the eddies likely to have? Unfortunately there are not enough spots on the sun at any one time to trace out satisfactorily the streamline structure of an eddy, so that we must be content with inferences from other fluid systems and other solar observations.

A pertinent example close to home is the earth's atmosphere, which has great belts of prevailing westerly winds in middle latitudes and a reverse flow of easterlies in a broad band around the equator. If these winds were viewed from outside the earth's atmosphere, the equatorial easterlies would represent a differential rotation flowing counter to the earth's rotation, just as the westerlies represent an acceleration comparable to the sun's equatorial acceleration. These differential rotations, it is now well established, are maintained by large horizontal eddies that transport momentum from the easterlies to the westerlies [see "The General Circulation of the Atmosphere," by Victor P. Starr; Scientific American, December, 1956].

The large eddies in the earth's atmosphere are associated with the high-pressure and low-pressure areas that are seen on daily weather maps. They have a characteristic asymmetric structure: they are tilted upstream and away from the maximum flow. They can take the form of waves or closed circulations [*see illustration at right above*]. In either case it is the tilt that gives the proper flux of momentum. It has also been demonstrated recently by Norman J. Macdonald of the Massachusetts Institute of Technology that the momentum flux from the easterlies to the westerlies in the earth's atmosphere can be computed by tracking the movements of the "highs" and "lows" found on weather maps in the same way that Ward used sunspots.

How the tilt of the wave influences the transport of momentum on the sun is best followed with the aid of a diagram [*see illustration at left above*]. Consider the points A and B in such a wave, depicted for the northern hemisphere of the sun. At point A on the back of the wave the fluid is moving toward the west limb and away from the equator. At these longitudes, therefore, zonal momentum is being carried away from the equatorial regions. Now consider the point B on the front of the wave at the same latitude as A. Here the motion is toward the west limb and toward the equator, so that zonal momentum at these longitudes is being carried *toward* the equator. Owing to the tilt of the wave the zonal momentum of fluid at B is larger than at A, so that the equatorward flow of momentum at B is also larger. When all points like B and A along a circle of latitude are considered together, it turns out that there is a net flux of zonal momentum toward the equator. The same argument applies in the sun's southern hemisphere, where the tilt of the wave is reversed from the tilt in the northern hemisphere. A similar argument would apply to circulation around a closed loop whose axis had the same kind of tilt as the waves we have been discussing. These schematic structures seem to us to be the most likely ones the solar eddies would have, if we could observe them directly.

Independent evidence for the existence of large wave disturbances in the horizontal circulation of the solar atmosphere has recently been obtained by H. H. Plaskett of the University of Oxford, using Doppler-shift measurements. Unfortunately the results obtained so far by this method have not shown whether or not the waves are tilted.

The large-scale magnetic regions observed by Bumba and Howard would appear to support this hypothesis of eddy structure. They tilt upstream away from the maximum of angular velocity at the equator and thus conform to the tilt

needed for equatorward transfer of angular momentum. Such a structure would conform to a well-known hydromagnetic effect. When a gas with high electrical conductivity is in the presence of a magnetic field, there is a strong tendency for the magnetic-field lines to "stick" to and so be dragged around by the gas. Thus if the streamlines of gas on the sun have tilted waves, the tilt should be apparent in the magnetic-field patterns as well. Another hypothesis for the shape of the bipolar magnetic regions has been proposed by Robert Leighton. He suggests that they are formed when strong sunspot fields are diffused by the motion of supergranules and the differential rotation [see "Magnetic Fields on the Quiet Sun," by William C. Livingston; Scientific American, November, 1966].

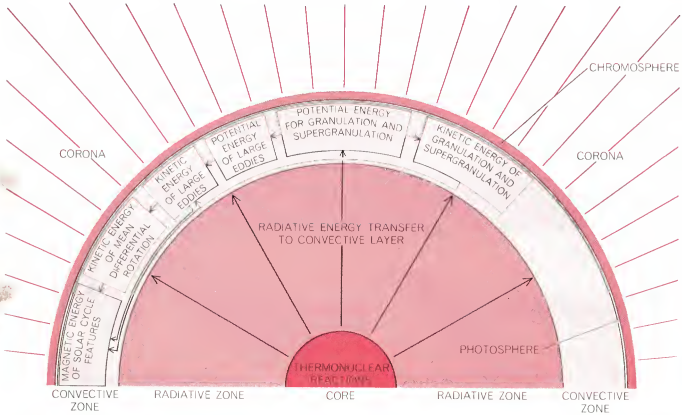
The net effect of the eddies, as we have visualized them, is to add momentum to the equatorial latitudes by subtracting it from higher latitudes. We have shown that this exchange necessarily implies that the eddies are losing energy to the differential rotation. We have also calculated the magnitude of this energy transfer and estimate that if it were cut off, the sun would rotate essentially as a unit within just a few months. The eddies must therefore draw on an energy source of their own. We cannot say with certainty what the immediate source is, but we believe there are three possibilities. Before turning to them, however, let us describe briefly what happens deeper in the sun.

All the activity one can observe on the sun must draw its energy ultimately from thermonuclear reactions deep in the solar interior, where temperatures must reach some tens of millions of degrees K. This energy is brought up by intense radiation to the levels where there are convection currents and visible forms of solar activity. The convection currents arise because radiation alone is not sufficient to move the energy to the surface and beyond. Masses of gas are heated in the solar depths, rise to the surface, cool, become heavier than their surroundings and sink again. In this way the potential energy provided by radiation is converted into kinetic energy in the form of convective motions. It is possible that the large eddies are also driven in this way, so that they can be regarded as "super" supergranules.

It seems likely to us, however, that the sun also has other mechanisms for exchanging energy that tap some of the energy from the convective motions and feed it into the large eddies. Two possibilities we can visualize for fueling the eddies are as follows.

The first is that the large eddies feed directly on the smaller convective motions through nonlinear processes that tap some of their kinetic energy. This is the direct opposite of a frictional decay process, in which big eddies break down into smaller and smaller ones until the kinetic energy of the originally organized motion becomes indistinguishable from the random kinetic energy of the molecules making up the fluid.

The second possibility is one in which the principal link between the convective motions and the large eddies is a process involving the transfer of potential energy rather than kinetic energy. It has been suggested, for example, that owing to an influence of the sun's mean rotation on the convective motions, the mean temperature at certain horizontal levels may not be the same at all latitudes. At these levels in the sun the solar gas might therefore be slightly lighter in some latitudes than in others. This would tend to create large-scale motions



HYPOTHETICAL ENERGY RELATIONS IN SUN as visualized by the authors are shown in this diagram. The arrows indicate fluxes of energy that relate to the sun's general circulation. It has not been directly demonstrated that the kinetic energy possessed by granules and supergranules provides kinetic energy for large eddies, but this seems distinctly possible. Note that all forms of kinetic energy shown contribute to the magnetic energy. This is probably also true of the kinetic energy associated with sunspots, which is not shown. Also not shown are losses of kinetic energy by true friction and losses of magnetic energy by electrical resistance.

that would transport heat horizontally toward the cooler latitudes. These motions would result when a layer of cold gas, moving sideways, sinks under a layer of warm gas. This is exactly what gives rise to the large weather systems in the earth's atmosphere. The sun pours into the earth's atmosphere more heat near the equator than near the poles; the large weather systems (cyclones) provide the mechanism for carrying the heat poleward. On the sun similar "weather" systems would have the tilted structure needed to transport momentum to the equator.

On this hypothesis the convective motions—observable as granules and supergranules—would be creating potential energy for motions of still larger scale, which would then be converted into the kinetic energy of the large eddies and ultimately into the kinetic energy of the equatorial acceleration. One of us (Gilman) has made a first attempt at a mathematical model for this process, making the assumption that some means exists for producing temperature differences over large regions below the solar surface. The results, while certainly not constituting proof, lend plausibility to the idea.

The model demonstrates how largely horizontal disturbances are formed in response to latitudinal temperature differences. It then shows how these disturbances assume the proper shape for maintaining the equatorial acceleration. In addition, as part of the results, these disturbances produce large-scale magnetic fields with gross properties not unlike the bipolar magnetic regions observed on the sun. The mathematical solution similarly shows vertical fields, predominantly of one sign, migrating toward the pole, qualitatively simulating the way in which unipolar magnetic regions are observed to form in high latitudes.

The studies done so far on the basis of this model have been mathematically somewhat limited and thus have been unable to reproduce the solar cycle, which evidently depends on a nonlinear feedback mechanism. Work is continuing on more ambitious models. Early results indicate that they may be able to simulate various gross features of the solar cycle, such as the unipolar and bipolar magnetic regions, together with the reversals of magnetic field that occur after each cycle. In any case, what has been achieved, using the earth's atmosphere as a guide to the general circulation of the solar atmosphere, has been most encouraging.

PERPETUAL WATERFALL, one of many "impossible objects" conceived by the contemporary Dutch artist Maurits C. Escher, seems to drive a mill wheel endlessly. Mills that produced enough power to recirculate the water needed to drive them were among the first perpetual motion machines proposed in Europe (*see bottom illustration on page 116*). Their designers did not realize that, because of the energy losses due to friction, no mill is capable of pumping all its water supply back to the uphill starting position.

PERPETUAL MOTION MACHINES

Over the past 400 years numerous inventors have proposed marvelous ways of getting something for nothing. All these proposals have foundered on either the first or the second law of thermodynamics

by Stanley W. Angrist

The interwoven tapestry of history sometimes displays odd relationships. Who would think, for example, that two medical men would be leading figures in the history of efforts to make a perpetual motion machine? One of them, the 17th-century English physician Robert Fludd, is usually mentioned as one of the first to propose a perpetual motion machine to do useful work. The other, the 19th-century German physician Julius Robert Mayer, was among those who established as a law of nature the conservation of energy, which dooms proposals such as Fludd's.

The notion of getting something for nothing that underlies all speculations about perpetual motion is as old as Archimedes and may be a good deal older. In classical times, however, there was a tendency to depend on supernatural power sources. A more down-to-earth approach to the subject grew out of economic considerations as the first labor-saving machines, in particular water mills, spread across Europe. Originally used to grind flour, water mills evolved rapidly in later Roman times. Although they were never especially popular in the Mediterranean area, quite the opposite was the case in western Europe. By A.D. 400 water-driven flour mills and sawmills were common in France. Twenty years after the Norman Conquest some 5,600 water mills were operating in 3,000 English communities, and before the end of the 14th century in England waterpower had been harnessed not only to grind flour and saw wood but also to tan leather, to full woolens and to grind pigments for paint. Soon almost every English manor that was situated on a stream—roughly a third of all the manors in the Domesday Book—had its own mill. Elsewhere floating mills were anchored in rivers and tidal mills stood in estuaries.

Villagers and townspeople who had no access to running water naturally sought alternative sources of power. One result was the windmill, a thoroughly practical invention. A less practical result was a series of proposals for closed-cycle water mills such as the one that Fludd put forward in 1618. The proposal must have seemed sensible enough at the time. If the water that turns a mill wheel could be collected from the race at the foot of the wheel and somehow put back into the reservoir above the wheel, the need for a source of running water would disappear. Centuries of experience had shown that mill wheels could turn big grindstones or raise heavy hammers. Why couldn't the wheel also drive a pump that would recycle the mill's water supply? In Fludd's day there was little reason to deny the possibility.

The same was true half a century later, when John Wilkins, Bishop of Chester and an early official of the Royal Society, put forward his views on the subject. In the 1670's Wilkins envisioned three natural power sources that might be harnessed to provide perpetual motion. These, in his words, were "Chymical Extractions," "Magnetical Virtues" and "the Natural Affection of Gravity."

Wilkins' third power source embraces the entire family of overbalanced wheels; that is, wheels that turn because they are perpetually heavier on one side than the other. He specifically mentioned only one formula for chemical extraction; its underlying concept may have arisen from a misunderstood observation of the ceaseless motion of small particles visible in a fluid that we know as Brownian movement. Wilkins also designed, but almost certainly never tried to build, a machine to utilize magnetic attraction. At no point, however, did he suggest a way of obtaining useful work out of the proposed perpetual motions.

As can be judged by Wilkins' leading role in the scientific community, speculation on perpetual motion machines was not yet considered a crackpot activity. Robert Boyle recounted in detail his examination of a fluid, compounded of bituminous oils and similar ingredients, that an engineer of his acquaintance had prepared as a charge for fire bombs. The engineer had mixed the ingredients over a fire and was surprised to find that days after the pot had been left to cool the fluid in it still swirled about. Keeping the pot in his laboratory for a time, Boyle observed that the oilier constituents of the fluid continued to stream, alternately spreading across the surface and then sinking out of sight. Again he made no proposal for harnessing the motion.

How was the tolerant attitude of early scientists toward perpetual motion transformed into today's skepticism? Clearly we now have far more theoretical knowledge and can make much more refined devices such as bearings, linkages and heat exchangers. Cannot this combination of talents close the apparently tiny gap between the designs of earlier times and the construction of actual working models? The answer, of course, is an emphatic no. For a perpetual motion machine to function, whatever its design, would require that it violate either the first or the second law of thermodynamics.

The first law of thermodynamics—the principle of energy conservation that Mayer helped to formulate—can be stated in various ways. One way of putting it says that a fixed amount of mechanical work always gives rise to the equivalent amount of heat. Thus energy can be converted from work into heat, but it can neither be created nor destroyed. There are more complex formulations of the first law but all eventually arrive at the

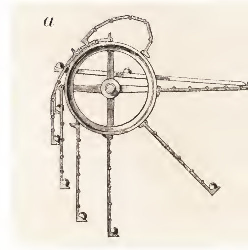
same conclusion: The total energy of the universe is constant.

Even before Mayer, pioneer studies of heat phenomena by the Scottish chemist Joseph Black and the American-born Count Rumford had helped to clear the way for deeper understanding. Black established the vital distinction between heat (as a quantity of something) and temperature (as an index of heat's intensity). The interrelationship of heat, energy and temperature is a complex one that can be explained by an analogy. After rain falls into a lake it is no longer rain but simply water; after heat is transferred to a body (because of a temperature difference between the cool body and its warm surroundings) it is no longer heat but simply energy. If the lake has no outlets, the rain raises the water level; if the body cannot get rid of energy, the heat transfer adds to its total energy and thereby raises its index of heat—its temperature.

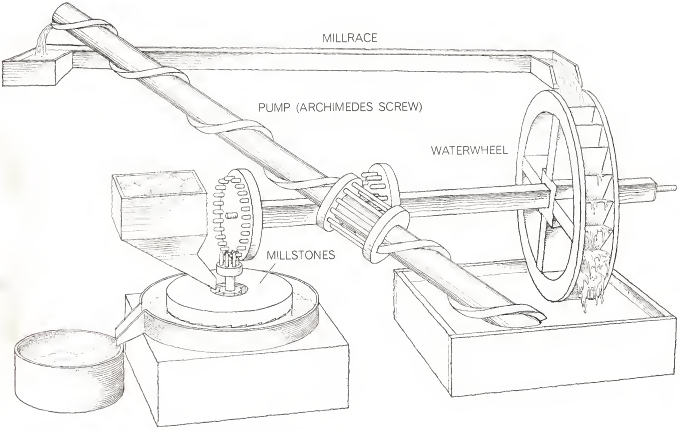
In Black's time variations in temperature and energy were attributed to the presence or absence of the intangible fluid called caloric. Rumford, in turn, struck a deathblow to the concept of caloric with his experiments in a Bavarian cannon foundry. Bringing water to a boil solely with the heat generated by the boring of a cannon barrel, he concluded that the heat was due to friction. This was the first demonstration of the connection between heat and work, but it was soon confirmed by Humphry Davy's experiment in which the rubbing together of two pieces of ice was shown to produce heat. It was a number of years, however, before the equivalence of work and heat was determined with any precision.

This brings us up to Mayer. In 1840, when he was 27, Mayer sailed from Rotterdam as ship's physician on the schooner *Java*, bound for the East Indies. Although it is doubtful that he knew anything about Black's work or Rumford's, he had brought along Antoine Laurent Lavoisier's treatise on chemistry, and he soon became fascinated by Lavoisier's suggestion that animal heat is generated by the slow internal combustion of food.

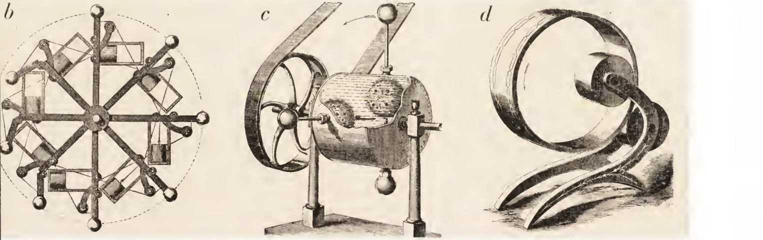
When the *Java* reached the East Indies, 28 of its crew were ill with fever. The treatment for fever in those days was to bleed the patient, and when Mayer did so, he observed that the crewmen's venous blood was bright red rather than the normal dark red—almost as red as arterial blood. Now, one of Lavoisier's comments was that, when the body is in warm surroundings, less internal combustion is required to keep it warm than when it is in cold ones. In support of this view he and others pointed to variations in the color of venous blood. Mayer concluded that his pa-



OVERBALANCED WHEELS have been the most common prime movers of perpetual motion machines. Just as the water's weight overbalances a mill wheel and makes it turn, so various means of apparently adding weight to one side of a wheel were expected



CLOSED-CYCLE MILL was proposed by the English physician Robert Fludd in 1618 as a source of perpetual power in areas that lacked streams. The fact that such devices could not work because they required a violation of the principle of energy conservation, formally known as the first law of thermodynamics, was not recognized by the scientific community until two centuries after Fludd.



to move the four machines shown above. The first device (*a*) was expected to turn when jointed arms, with weights that rolled to their ends, were extended on one side; actually the wheel remains exactly balanced, whether or not the arms are extended. A much more complex wheel (*b*) was designed with the same objective. Like *a*, however, it is actually in balance in spite of its shifting weights. A pair of buoys within a water-filled drum were expected to move weights that would overbalance the next device (*c*). Finally (*d*), a starkly simple design reflects the inventor's conviction that his overbalanced wheel rim would spin between two rollers in spite of its lack of any support. These engravings and four on the following pages appeared in early issues of SCIENTIFIC AMERICAN.

tients' venous blood looked like arterial blood because, like arterial blood, it had a high content of oxygen. It seemed that in the tropical East Indies the crewmen's bodies did not consume as much oxygen as they did in cooler latitudes.

At this point Mayer went a step beyond Lavoisier to conjecture that the body heat evolved by the metabolism of food should be exactly balanced by a combination of two opposing factors. These were, first, the heat lost by the body to its surroundings and, second, the work the body performed. Mayer was soon saying that heat and work are merely different manifestations of energy (which he called "force"), and that the two manifestations are equivalent.

The young physician was not able to obtain experimental proof of his conjecture; he lacked both money and laboratory facilities. He did, however, analyze data collected by other investigators on the specific heat of air, and he managed to calculate a numerical relation between heat and units of mechanical work. In effect he had determined the mechanical equivalent of heat. He offered an account of his work to the foremost scientific journal of his day, *Annalen der Physik und Chemie*, but it was refused. In 1842 a revised account appeared in another journal, and Mayer's version of the first law of thermodynamics was formally put forward. "Once in existence," he wrote, "force cannot be annihilated; it can only change its form."

James Prescott Joule, the son of a prosperous English brewer, was born four years later than Mayer. Joule studied chemistry in Manchester with John Dalton, but soon he developed an enthusiasm for experiments in electricity and electromagnetism, a field in which he was largely self-taught. In the early 1840's he carefully measured the amount of work required to raise the temperature of a pound of water from 60 degrees Fahrenheit to 61 degrees. Joule announced his result in 1843: the amount of mechanical energy required was 838 foot-pounds. In later years he refined this figure to 772 foot-pounds, a value remarkably close to today's standard (778.16 foot-pounds).

Joule had thus quantified the relation between work and heat that Mayer had propounded. Four more years were to elapse, however, before a third young investigator, Hermann von Helmholtz, convinced the international scientific community that the first law was a valid generalization. In 1847, when he was 26, Helmholtz presented his formulation of the first law before the Physical Society of Berlin in a paper titled "On the Conservation of Force." He began his analysis by declaring that perpetual motion machines were axiomatically impossible. In physics, as in mathematics, axioms are distinct from theorems. A theorem is a conclusion that is logically deduced from an axiom. An axiom does not require logical proof. The validity of a physical axiom can be based instead on repeated observations of nature. Thus Helmholtz did not need to prove his axiom; it was enough to point out that no one had yet built a successful perpetual motion machine. Helmholtz observed further that he was not alone in his view. Nicolas Léonard Sadi Carnot, an early student of the theoretical basis for the steam engine, had started with a similar axiom and had reached a number of significant conclusions concerning the dynamics of heat. As we shall see, Carnot's work, particularly his 1824 study "Reflections on the Motive Power of Heat," forms the basis of the second law of thermodynamics.

Proceeding from his axiom, Helmholtz next showed that the failure of perpetual motion machines led logically to the conclusion that energy is always conserved. He went on to demonstrate that both heat (regarded as small-scale motion) and work (regarded as large-scale motion) were forms of energy and that what was conserved was the total of the two forms rather than either heat or work taken separately. Helmholtz showed that the findings of Joule's experiments were in general agreement with calculations of the kind made by Mayer. Like Mayer, Helmholtz submitted his paper to *Annalen der Physik und Chemie*, and it too was refused.

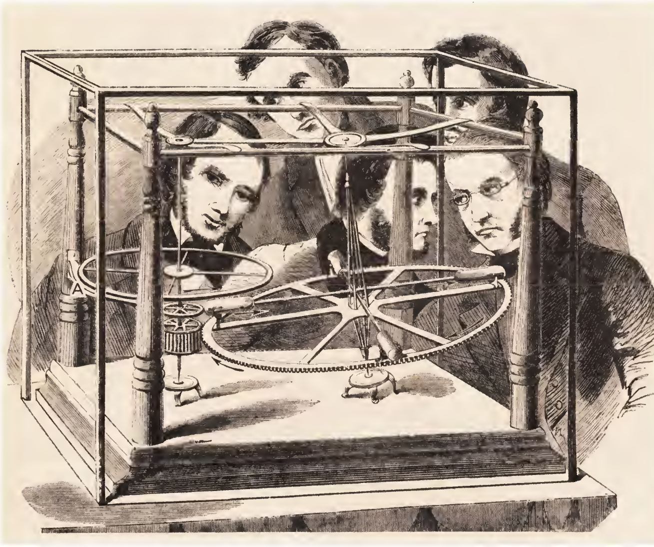
I have given this brief history of the first law because it is the law that most would-be inventors of perpetual motion machines attempt to evade. Their expectation is that more energy can be wrung out of some device incorporating falling or turning bodies than is required to restore the device to its original state. Curiously one of the most persistent proposals is Fludd's closed-cycle water mill. As late as 1871 an American patent attorney noted with some asperity that inventors submitted one or another vari-

ation on Fludd's mill to him every year, inquiring whether the concept was patentable. Over the years, however, devices that depended for their power on overbalanced wheels gradually abandoned running water in favor of ingenious weight-shifting systems.

Many inventors have preferred power sources more sophisticated than the overbalanced wheel. Both early and late they have turned to magnets, at first natural magnets and then electrically powered ones. Bishop Wilkins' design for a magnetic device depended on a lodestone, which was to be strong enough to pull an iron ball up a ramp. Just before the ball had climbed all the way up to the lodestone, it would drop through a hole and roll back down a curved second ramp. The ball would then pass through a door and reach the first ramp again, where it would resume its upward journey. It is easy enough to find the flaw in Wilkins' proposal today: any lodestone strong enough to pull the ball up the ramp would be too strong to let it fall back to its starting point.

A 19th-century device solved a similar problem by incorporating an electromagnet that was alternately turned on and off. When the circuit to the magnet was closed, the magnet's attraction was supposed to pull a connecting rod that acted through a crank to impart rotary motion to a disk. The spinning of the disk between two brushes was then expected to generate enough electricity to energize the magnet. Once the machine was started by hand the inventor expected it to run forever, or at least until the contact points on the switches wore out. As so often happens in the design of perpetual motion machines, the inventor had made no allowance for the energy lost to friction and, in this case, to electrical resistance as well.

It is scarcely surprising that the chimera of perpetual motion has attracted not only savants and optimists but also rascals. One of the many outright frauds in the history of perpetual motion machines was perhaps the most elegant overbalanced wheel ever built. It was the work of a skilled Connecticut machinist, E. P. Willis. A large gear wheel, mounted at an angle to the horizontal and fitted with a complex system of weights, purportedly drove a smaller hollow flywheel. After the machine had attracted much attention in New Haven, where Willis charged admission for viewing it, he moved it to New York in 1856. There the same attorney who was to comment on the perpetual rediscovery of Fludd's water mill went to see it. The exhibitors, he noted, were careful



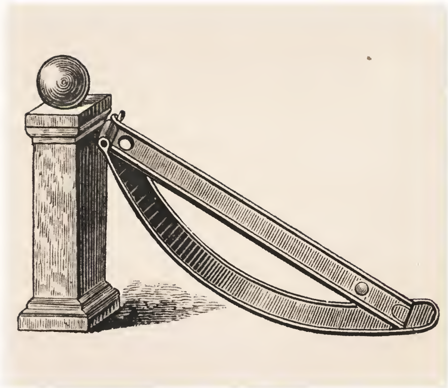
FRAUDULENT MACHINE that purported to demonstrate perpetual motion was built by a Connecticut machinist in the 1850's. Ostensibly each pair of rod-linked weights that rested atop the tilted wheel (*right*) was shifted in position as the wheel turned, so that the uphill weight extended beyond the wheel's perimeter. The resulting imbalance was said to be sufficient to keep the wheel turning and to drive a flywheel (*left*). Actually compressed air passed through a strut (*A, far left*), turning both of the wheels.

not to claim that Willis had achieved perpetual motion; rather, they challenged any visitor to provide another explanation for the machine's motion. Although a glass case kept viewers from inspecting the machine closely, the attorney noted that there was a suspiciously nonfunctional strut below the edge of the hollow flywheel. Evidently a steady flow of compressed air, undetectable outside the glass case, kept the flywheel turning. Thus it was actually the flywheel that drove the overbalanced wheel, rather than the reverse.

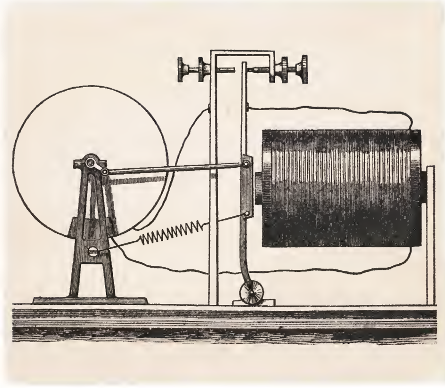
The Willis fraud, Fludd's water mill and all similar devices are based on the assumption that the first law of thermodynamics can be violated. Some perpetual motion machines, however, do not violate the first law; neither friction nor electrical resistance is a significant problem in their design. They are nonetheless impossibilities because they attempt instead to circumvent the second law of thermodynamics.

The foundation of the second law was laid down by the observations of Carnot, and the law was first fully formulated by the German physicist Rudolf Clausius. The first law, as we have seen, demonstrates that a fixed amount of mechanical work can always be converted into the equivalent amount of heat. But the most casual observation of a heat engine in operation—for example a steam engine—makes it plain that the reverse of the first law's axiom is not precisely true: a fixed amount of heat cannot be completely converted into the same amount of work. When heat is transformed into work, some of the initial energy is unavoidably wasted. In the case of a real steam engine operating in the real world, some of the wasted energy goes to overcoming friction, some is lost through warming the engine and the surrounding atmosphere, some through leakage and some through other avenues of dissipation.

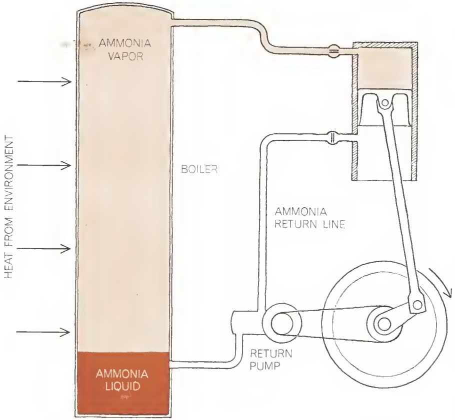
Carnot wanted to find out whether improved design could eliminate all steam engine losses. He created in his imagination an ideal engine; it was leakproof, completely insulated and frictionless. He then ran the imaginary engine through a full operating "cycle" (a concept, by the way, that Carnot was the first to develop). In one ideal cycle water is heated until it vaporizes into steam, and the pressure of the steam forces the engine's piston to move; the cycle is completed when the expanded steam cools and condenses into water again, allowing the piston to return to

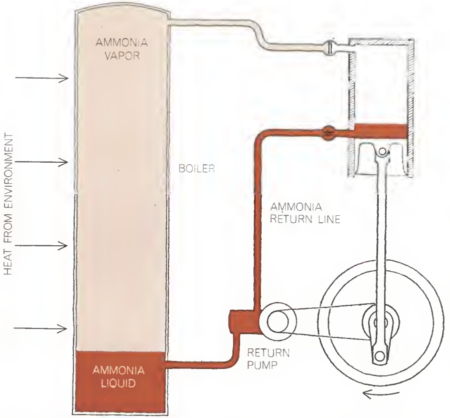


PERPETUAL MOTION powered by "Magnetical Virtues" was to be achieved by a steel bullet as it rolled up and down a pair of ramps according to a design proposed by the Bishop of Chester in the 1670's. The lodestone placed on the top of the pedestal was expected to draw the bullet up the straight ramp, whereupon it would fall through a hole and roll back to its starting position. The bishop did not propose harnessing the device to obtain power.



PERPETUAL MOTION powered by electricity was often favored by 19th-century inventors. In this design the attraction of an electromagnet worked through a crank to turn a wheel; the wheel's rotation was then supposed to generate enough electricity to work the magnet. As usual the inventor neglected to allow for the losses from friction and resistance.





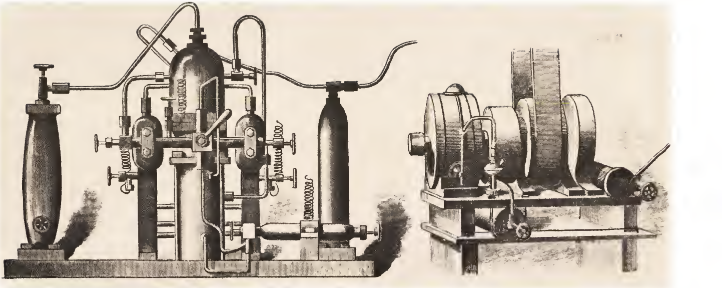
AMMONIA ENGINE of the 1880's, designed by John Gamgee, was based on the expectation that free power would be produced because heat transferred from the surroundings would turn the ammonia from liquid to gas. The gas pressure is enough to drive a piston (*top*). When the gas then expanded in the cylinder (*bottom*), the inventor expected that it would condense spontaneously and return to the boiler as a liquid to repeat the cycle. He did not anticipate the need to refrigerate the return side of his engine in order to convert the ammonia gas to liquid. The energy needed to do this, of course, is more than the engine produces.

its starting position. Thinking through the steps in this ideal cycle, Carnot realized that a complete conversion of heat into work was impossible; an unavoidable loss of thermal energy occurred in the process of cooling and condensation.

The language Carnot used to state his conclusions is strange to our ears because, like others in his day, he talked about heat in terms of caloric. What he had to say was nonetheless the earliest statement of the second law. The transformation of heat into motive power, Carnot wrote, "is fixed solely by the temperature of the bodies between which is effected . . . the transfer of the caloric." This is to say that, in order to do work, heat must "run downhill" as water does and, just as with water, the farther it runs downhill, the greater the amount of work it does. This is the concept we express today by saying that heat must be transferred from a higher temperature to a lower one to do work.

Building on Carnot, Clausius applied the word "entropy" (from the Greek for "turning") to the index used to measure the amount of heat that is unavoidably lost. The modern formulation of the second law that says that entropy always increases arises from the earlier realization that heat is a downhill flow. Because the supply of energy in the universe is a constant that cannot be increased or decreased, and because at the same time the downhill flow of heat is accompanied by inevitable losses, a time will inevitably come when the entire universe will be at the same temperature. With no more hills of heat and therefore, in Carnot's terms, no further transfers of caloric, there can be no work. This inevitable end, sometimes called the "heat death" of the universe, concerns us here because perpetual motion machines that attempt to violate the second law are expected to achieve a localized halt in the inevitable increase of entropy and produce a decrease of entropy instead.

The fact that, on the average, entropy continually increases does not, of course, rule out the possibility that occasional local decreases of entropy can take place. It is only that the odds against such an event are extraordinarily long. The bed of a river could suddenly cool, yielding its energy to the running water, and this energy could be applied in some way to make the water run uphill. But riverbeds do not cool and water does not run uphill. A similar loan of thermal energy from the river's environment could al-



"GENERATOR" AND "MOTOR" of a supposed perpetual motion device were exhibited in Philadelphia for more than a decade late in the 19th century. The inventor, John E. W. Keely, contended that the generator (*left*) turned tap water into high-pressure "etheric vapor" when "vibratory energy" was applied. After Keely's death the totally fraudulent device was found to run on compressed air.

low the water to dissociate spontaneously into hydrogen and oxygen. But the water does not dissociate spontaneously. Furthermore, an old man on the riverbank, watching the water flow by, could grow younger rather than older, but he doesn't. Rivers continue to flow downhill, H_2O remains water and man inevitably ages. The chemist Henry A. Bent has calculated the odds against a local reversal of entropy, specifically the probability that one calorie of thermal energy could be converted completely into work. His result can be expressed in terms of a familiar statistical example: the probability that a group of monkeys hitting typewriter keys at random could produce the works of Shakespeare. According to Bent's calculation, the likelihood of such a calorie conversion is about the same as the probability that the monkeys would produce Shakespeare's works 15 quadrillion times in succession without error.

It is against these odds that the would-be inventor of a perpetual motion heat engine must struggle. One such inventor was John Gamgee, who was active in Washington, D.C., during the 1880's. He developed a heat engine that he called the zeromotor because its normal operating temperature was zero degrees centigrade. The zeromotor was not unlike an ordinary steam engine except that the working fluid was ammonia rather than water. Liquid ammonia vaporizes into a gas at a low temperature, and at zero degrees C. the gas exerts a pressure of four atmospheres. Gamgee reasoned that the transfer of heat from the environment, rather than the energy supplied by the combustion of fuel, would be enough to transform the ammonia working fluid from a liquid to a gas. He reasoned further that the ammonia gas, on driving the piston back and expanding, would cool, condense and drain into a reservoir, whereupon the cycle could begin again [*see illustration on opposite page*].

Anyone with the slightest knowledge of Carnot's cycle, let alone the second law of thermodynamics, could scarcely take such an idea seriously, yet Gamgee and his supporters were undoubtedly sincere. They had either incorrectly calculated or failed to calculate the zeromotor's temperature requirements. The heat transfer from the environment was indeed sufficient to convert ammonia from a liquid to a gas, but this advantage is nullified in the system as a whole by the cooling of the gas on expansion. Starting at zero degrees C. and a pressure of four atmospheres, the temperature of the gas has fallen to -33 degrees by the time its volume has quadrupled. If the gas is to condense into a liquid, both the condenser and the reservoir must be at a temperature lower than -33 degrees. Gamgee had not provided for this cooling, and if he had, the cooling process would of course have required more energy than the zeromotor could produce.

One of Gamgee's principal supporters was B. F. Isherwood, Chief Engineer of the U.S. Navy. In March, 1881, Isherwood reported favorably on the zeromotor to the Secretary of the Navy, in spite of the fact that scholars had pointed out that the engine fatally violated the second law. Official Washington came close to embracing the inventor. The Secretary of the Navy was not the only high official who inspected a model of the zeromotor with interest; so did other Cabinet members and President Garfield himself. Isherwood's gullibility may be hard to understand, but not his interest. This was an era when in order to keep the U.S. fleet at sea it was necessary to maintain a complicated and expensive network of coaling stations abroad. If the Gamgee engine had worked, coaling stations could have been forgotten and all the energy the Navy would have needed to power its fleet could have been provided by the thermal energy contained in the seawater in which the ships floated.

The surprisingly wide acceptance of proposals such as Gamgee's can be explained, of course, by general ignorance of known principles. As early as 1775 the French Academy of Sciences passed a resolution refusing to entertain any future communications concerning perpetual motion. The U.S. Patent Office has long declined to examine applications for patents covering perpetual motion machines unless the applicant furnishes a working model or "other demonstration...of the operativeness of the invention," a ruling that has produced much hostile correspondence but no working models. In spite of such official opposition public sophistication regarding the possibility of building perpetual

motion machines was slow to develop.

Perhaps the most ingenious, and certainly the longest-lived, swindle involving a supposed perpetual motion machine began in 1875, when John E. W. Keely unveiled a combined "generator" and engine at his home in Philadelphia. There was nothing unusual about Keely's engine, which was a variation on the conventional steam engine. Keely's generator, however, was extraordinary. It was an elaborate combination of metal globes, tubes, petcocks, nozzles, valves and gauges, but its operation was deceptively simple. Keely would blow into a nozzle for half a minute and then pour five gallons of tap water into the generator through the same nozzle. After turning various petcocks and valves he would show onlookers a pressure gauge indicating that the generator was full of a mysterious "vapor" with a pressure of 10,000 pounds per square inch. "People have no idea of the power in water," Keely would say. "A bucket of water has enough of this vapor to produce a power sufficient to move the world out of its course."

Keely and his associates formed the Keely Motor Company, capitalized at $1 million. They raised much of the money from gullible New York businessmen. As the years passed, although no engines other than the first one were ever built, Keely's showmanship became more polished. By 1881 he had begun to attribute the production of vapor to "vibratory energy," and he would "vivify" the vapor during demonstrations with a giant tuning fork. By 1884 he had so mastered what he now called the "etheric vapor" or the "interatomic ether" that he demonstrated a new device: a cannon, complete with a "vibrator" near the breech, that was capable of propelling a ball 500 yards with a muzzle velocity of 500 feet per second.

Keely died in 1898. The son of one of his major backers promptly rented his Philadelphia house and explored the premises in the company of reputable witnesses, seeking evidence of fraud. Under the floor of the house the searchers found a three-ton metal tank that had evidently served as a reservoir for compressed air. In the walls were found quantities of brass tubing, and a false ceiling suggested the means by which Keely and his associates had conducted the compressed air to his generator. Whatever other laws he may have broken in his long career, Keely had left the first and second laws of thermodynamics inviolate.

The Hasselblad System...
and why a certain kind of person might fall in love with it.

There are many people who buy and use a car just to get from point A to point B, and who buy any piece of mechanical equipment strictly on the basis of it performing a particular function with the minimum of involvement on their part.

For this kind of person there is a certain kind of camera, the kind that does all the thinking for him. Film is loaded in the form of a cartridge, a button is pressed...and that's all; total non-involvement.

Now don't misunderstand us, we are not criticizing either the person or the camera. They both will probably be very happy with each other... But, there is another kind of person. The kind who buys a fine automobile, not just to get from point A to point B, but also for the great pleasure he gets from actually driving it. For this kind of person there is also a certain kind of camera... the Hasselblad... A camera that doesn't do all the thinking for you.

The Hasselblad is a camera for the kind of person who buys a piece of mechanical equipment, not just to perform a particular function, but also for other, almost intangible, reasons. For the feel, the look, the touch, sometimes even the smell of it. Certainly he could give you very sound, logical reasons for buying it and probably spending much more money than he would pay for the simpler, non-involving "push-button" model, but none of these would be the real reasons.

The real reason is very simple—he fell in love with it. Many men (and a very few lucky women) fall in love with a beautiful machine. To these men, there is something about a piece of equipment that not only looks, but feels good and performs its function better, because it's designed and built better than anything else in the world

And that's what the Hasselblad is. The best designed and built camera in the world.

Many people have bought a Hasselblad after just holding one in their hands for a couple of minutes. They seem to know instinctively that it will take great photographs. And, if even further proof is needed, not only has a Hasselblad been carried on every NASA space flight, but more top professional photographers use Hasselblad than any other camera in the world.

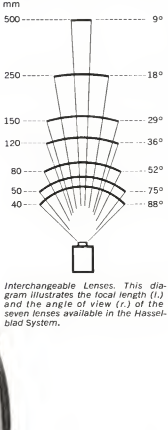
The basic Hasselblad camera is really just part of a completely integrated and interchangeable system of camera bodies, film magazines, lenses and accessories.

The film format used in the Hasselblad System is 2¼" square. This has been described as the "ideal" format, and with good reason. It's big enough to give you pictures of superb quality and definition, and yet small enough to allow the design and physical shape of the camera to be as compact as it is.

The Hasselblad uses the single lens reflex viewing system. The beauty of this method is that you see the object you are going to photograph on a large 2¼" square ground glass viewing screen, as you look through the actual lens that will take the picture, so you always know exactly how your finished picture will turn out.

There are three bodies in the Hasselblad System, each one designed and constructed to perform its own particular function better than any other camera of its type.

Firstly, the 500C. This could almost be called the "workhorse" of the Hasselblad System. It is the standard body in the System and takes all the lenses and magazines that are available for the Hasselblad. No single camera has been used and praised more by the top professional and amateur photographers than the 500C. The other two bodies are more "special purpose" cameras. The 500EL, which is an electrically driven camera allowing for rapid exposures and remote control, and the Superwide C wide angle camera. No other camera using the 2¼" square format has as wide an angle of view as the Superwide C. On its introduction, this camera was hailed as a breakthrough in camera design. There are seven lenses



Interchangeable Lenses. This diagram illustrates the focal length (l.) and the angle of view (r.) of the seven lenses available in the Hasselblad System.

in the Hasselblad System, all by Carl Zeiss, makers of superb quality optical glass for generations. The lenses range from a 40mm wide angle, to a 500mm telephoto. Every lens has a built in Synchro Compur shutter with provision for flash and strobe synchronization at all 10 shutter speeds, from 1/500 of a second to 1 second.

One of the most striking features of the Hasselblad System is the interchangeable film magazines, each one of superb design and construction. The beauty of these magazines is that with just one camera body, a photographer can shoot pictures in black and white. Then, before finishing the roll, change to a magazine loaded with color, shoot a few color shots, then go back to black and white film. One magazine even allows you to make 70 exposures on one roll of film. Hasselblad was the first camera system to offer the advântage of interchangeable magazines.

There are many many accessories in the Hasselblad System, each one designed and built to the same extreme standards of quality and craftsmanship that Hasselblad has become famous for.

Shown below are just a few items in the System.

Like all good things in life, the Hasselblad is expensive, but if you're the kind of person we have been talking about (and you wouldn't have read this far if you weren't) then, who knows, with this kind of camera, perhaps you could live on love alone.

If you would like more information and a free 40 page catalogue, write to: Paillard Incorporated, 1900 Lower Rd., Linden, New Jersey 07036

HASSELBLAD

MATHEMATICAL GAMES

The beauties of the square, as expounded by Dr. Matrix to rehabilitate the hippie

by Martin Gardner

When the hippie scene started to crash last fall, thousands of flower children found themselves up tight and no place to glo. Daisy Jones, a minibrained daughter of a friend of mine in Connecticut, finally wandered home. So shaken had she been by the bad vibes around Tompkins Square that she found it impossible to readjust to her former life.

Then Mr. Jones heard about Squaresville.

"Squaresville?" I asked when he told me this in November.

"Yes. It's a hippie rehabilitation center in the northeast corner of Westchester County. Beautiful spot. A psychotherapist named Hawk—Irving J. Hawk—has taken over a new housing development there near Peak Lake."

The "Irving J." made my ears prick up. "Is Dr. Hawk a tall, thin man with a hawk nose and green eyes?"

"Why yes," Jones said. "You know him?"

"I think I do."

"I'd never heard of him before but his therapy seems to work. Daisy went there for nine weeks of 'straightening.' Cost us $1,024 but it was worth every penny. She's back in high school now and making straight A's."

The next morning I drove to Squaresville. Iva, Dr. Matrix' half-Japanese daughter, seemed surprised and a trifle annoyed when I came into the reception room. "Please," she whispered so that others in the room would not hear, "don't give us away." Then in a normal voice she added, "I'm Mary Jane Grok, the doctor's secretary. Have a seat; Dr. Hawk will see you as soon as possible."

Iva's black hair was short and neatly trimmed. Large square-shaped red ceramic earrings dangled from her ear lobes.

When my turn came to enter Dr. Matrix' office, I found him wearing a gray flannel suit, his face clean-shaven, his gray hair cut in the latest Madison Avenue style. On the dark-paneled wall behind him was a huge square-framed print of Norman Rockwell's portrait of President Johnson. A square poster on the left wall said in large letters: "Be happy, not hippie—learn to play the game." On the opposite wall a similar sign said: "It is better to be rich and healthy than poor and sick."

"I didn't expect you to find us so soon," Dr. Matrix said, pushing a square cigarette box toward me. "Sit down. Have some tar and nicotine."

Squaresville's population, he informed me, was kept at 361, the square of 19, the average age of the patients. When a male hippie arrived, his beard was shaved off and he was given a crewcut. The girls had their hair cut short and coiffured by professional hairdressers. Each hippie was outfitted with conventional clothes, given a wristwatch and assigned to a room in one of Squaresville's 49 identical split-level houses.

"The nitty-gritty of our treatment," Dr. Matrix went on, "is intensive conditioning in the art of square living. Each room has color television. No one is allowed to move a mattress to the floor or to squat cross-legged. The rooms are kept supplied with free cigarettes. Everyone has three square meals a day, including a compulsory martini before dinner."

"I've been told," I said, "that mathematics is part of your therapy."

"Yes, an essential part. When these freaked-out youngsters come to us, they've been flying for months in a dreamworld. We bring them down to earth by teaching them that there are laws of nature, laws that can be ignored only at great peril. We show them that they can be as high as they like but that if they jump out a window they won't float gently down—the law of gravity will kill them. We teach them that there are also laws of health and laws of morality. The life game, like any other game, is no game at all without rules."

"I still don't see how mathematics is involved."

"I'm getting to that. The hippies, you see, have learned to overvalue disorder. The random curves of their psychedelic art and the whirling patterns inside their circular mandalas are symbolic of this. Our job is to teach them the beauties of the straight-sided square. We explain how uncurved borders make it possible for squares to fit together without waste space. We show that, as the world population increases, square shapes become necessary for packing into cities, suburbs, subways, commuter trains. In its interior every square has secret incommensurable qualities, and as many curves as you like can be drawn inside it, but its straight exterior is absolutely essential for close packing."

"I'm beginning to anticipate," I said. "The numerical equivalent of the square is of course the square number."

"Precisely. We begin our conditioning at the lowest levels of arithmetic. First we teach our patients that a square of side n must have an area of n squared. Then slowly, by displaying the elegant properties of square numbers, we convince them that *two* power is much more beautiful than flower power. We start with simple things, such as the fact that no square number can end in 2, 3, 7 or 8, and that the last digits of squares, as you go up the ladder, endlessly repeat the palindromic cycle 1, 4, 9, 6, 25, 6, 9, 4, 1, with a double 0 separating each cycle. We show how to find the digital root of a number by adding its digits and casting out nines until only one digit is left. All squares, they discover, have digital roots of 1, 4, 7 or 9. These also repeat a palindromic cycle, 1, 4, 9, 7, 7, 9, 4, 1, only now the cycles are punctuated by 9's instead of double 0's."

"Those are useful rules for puzzle buffs," I said. "I remember one instance. I knew that 12,345,678,987,654,321 is the square of 111,111,111 and I wondered if 98,765,432,123,456,789 could also be a square. I wasted 20 minutes extracting the square root before I remembered the digital-root test. Since the number has a digital root of 8, it can't be a square."

Dr. Matrix nodded. "We teach patients that if a square's last two digits are alike and not 0, they must be 44, and that 144 is the smallest example."

"Can a square end in three 4's?"

"Yes. The smallest is 1,444. Then comes a big jump. You might ask your readers to see if they can find the next-smallest example—perhaps a formula that generates all such numbers."

"Excellent," I said, jotting this in my notebook. "And do any squares end in four 4's?"

Dr. Matrix shook his head. "Three is

the maximum. Since neither 44 nor 444 is a square, we see that no square of two or more digits can have all its digits alike. It is also true that no square of two or more digits can have all its digits odd. Your readers might enjoy proving it."

When I had finished writing this down, Dr. Matrix said: "Here's a little-known curiosity about 13. Its square is 169. The reverse of 169 is 961, and the square root of 961 is 31, the reverse of 13. The product of 169 and 961 is 162,409, another square. I once proved that if any number and its reverse are different, their product is square only if both numbers are square, but that's by the way. The sum of the digits in 169 is 16. The sum of the digits in 13 is 4, the square root of 16."

"It's too much! You're blowing my mind!"

"There's a topper," Dr. Matrix said, smiling slightly. "If we ignore palindromic numbers such as 11 and 22, and numbers ending in 0 such as 10, 20, 30, then there's one other pair of two-digit numbers with the same set of properties as 13 and 31."

"I'll ask my readers that too," I said. "I know a great deal of work has been done on square numbers that contain all the digits just once, with or without 0, and all of them twice, and so on. Have you done any work along such lines?"

"No, but let me mention a remarkable discovery sent to me recently by J. Malherbe, a Parisian mathematician I knew many years ago when I studied in France under the great Bourbaki. The two numbers 57,321 and 60,984 together contain the 10 digits. And each of the squares of those numbers, 3,285,697,041 and 3,719,048,256, is made up of just the 10 digits."

"Can a square be exactly twice another square?"

"No. Nor can it be any prime multiple. But I'm more interested in less familiar corners of square theory. Have you heard of automorphic numbers?"

I shook my head.

"An automorphic number is one that reappears at the tail end of its square. For example, 5 and 6 are the only single-digit automorphs except for the trivial cases of 0 and 1. The two-digit automorphs are 25, with a square of 625, and 76, with a square of 5,776. The three-digit automorphs are 625 and 376. Our patients find these numbers symbolic of the fact that, even though they'll soon acquire the façade of a square, they can preserve their unique ulterior identity."

"I observe," I said, "that larger automorphs are obtained by adding digits to the front of the two automorphs of next-lowest order. Are there two automorphs for any given number of digits?"

"Two at the most but sometimes only one. For example, 9,376 is the only four-digit example. We assume, of course, that no number begins with 0. And 90,625 is the only five-digit automorph."

"Are there automorphic numbers in all number systems?"

"No. If the base is a prime or a power of a prime, there are no automorphs except 0 and 1."

I thought for a moment. "Then base 6 would be the first system with true automorphs?"

"Yes. Base 10 is next. Maybe your readers would like to search for the two two-digit automorphs in base 6."

"Is there a limit to an automorph's size?"

Dr. Matrix assured me there was not. He borrowed my notebook and wrote from memory the 100-digit base-10 automorph shown below. It had been found in 1964, he said, along with its 100-digit mate, by R. A. Fairbairn of Willowdale, Ont., who used only a desk adding machine and a few clever short-cuts. (The two monstrous numbers were first disclosed by J. A. H. Hunter in the *Fibonacci Quarterly,* Vol. 2, October, 1964, page 230.) More recently, Dr. Matrix said, Vernon deGuerre, attending a computer course at York University in Toronto, had used the university's computer to extend both numbers leftward to 500 digits, but his results have not yet been published.

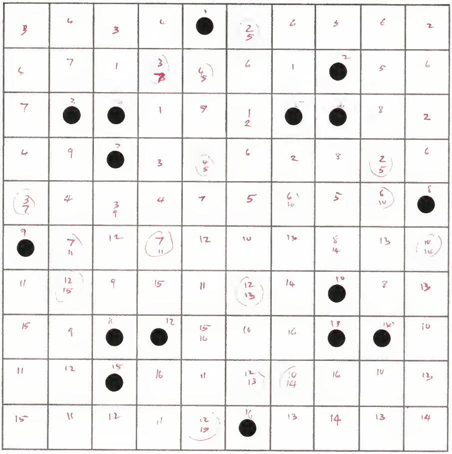
Dr. Matrix showed me a beautiful relation between pairs of automorphs of the same length. If you know one, you can immediately write the other. Readers are invited to search for this relation and use it to construct the second 100-digit base-10 automorph before it is given next month along with the answers to the preceding problems.

"Of course most of our hippies, particularly the chicks, get a headache when they study arithmetic," Dr. Matrix said. "You'd be surprised, though, how many of them develop a strong interest in squares once they get over their hippie withdrawal symptoms." He glanced at his square wristwatch. "Holy McNamara! Time for lunch. You'll join us?"

Dr. Matrix, Iva and I walked across the large quadrangle framed by the 49 houses of Squaresville. It was mid-November but the grass was still green and impeccably cut. Square signs read "Keep off grass," but Iva explained that this referred to marijuana and did not pro-

3	9	5	3	0	0	7	3	1	9
1	0	8	1	6	9	8	0	2	9
3	8	5	0	9	8	9	0	0	6
2	1	6	6	5	0	9	5	8	0
8	6	3	8	1	1	0	0	0	5
5	7	4	2	3	4	2	3	2	3
0	8	9	6	1	0	9	0	0	4
1	0	6	6	1	9	9	7	7	3
9	2	2	5	6	2	5	9	9	1
8	2	1	2	8	9	0	6	2	5

One of the two 100-digit automorphic numbers



Newly discovered second solution to a knight problem

hibit our walking diagonally across the lawn.

When we entered the dining room of Eisenhower Hall, 361 ex-hippies were standing and singing "America the Beautiful." Iva led us to a square table in a section reserved for the staff. Dr. Matrix gave a blessing and everyone sat.

"What's their program for the rest of the day?" I asked.

"Today's Saturday," Iva replied. "There are no classes. The boys and girls will attend a showing of *The Sound of Music*, then go back to their rooms to watch television until dinnertime. There's a square dance this evening with music by Lawrence Welk and his orchestra. Tomorrow morning everyone goes to chapel. The sermon is usually preached by our staff minister—we call him the Chief Tee Hee of our anti-neo-American Church—but tomorrow we have a guest minister. Dr. Norman Vincent Peale is preaching on 'Get in Gear with God.' "

"Do you have any trouble finding prominent guest speakers?"

"No, they're always pleased to help out in a square cause. Last week we had a sermon on the evils of Methedrine by Dr. Ellis D.—the hippies call him 'L.S.D.'—Sox, the public health director of San Francisco. Next week Dean Rusk will tell us why we are in Vietnam."

After coffee and a square-cut slice of apple pie the boys and girls stood up to chant the 16-word Squaresville law: "Good squares are trustworthy, loyal, helpful, friendly, courteous, kind, obedient, cheerful, thrifty, brave, clean and reverent." After a chorus of "God Bless America" Dr. Matrix dismissed them.

The cats and birds looked clean and reverent as they filed politely past us. Each wore a square button. I noted one of the legends: "Love not Haight."

Dr. Matrix pointed to a clean-cut young man who saluted us as he walked by. "You should have seen him when he first arrived. He was a digger in the East Village who called himself Launcelot—barefoot, with long pigtails, steel-rimmed glasses and L-U-V painted on his forehead with lipstick. For three weeks all he ever said was 'Hey man.' His father in Tulsa had been sending him bread but he flung it all in $10 bills at the heads of brokers on the floor of the Stock Exchange. When he wired home, 'No mon, no fun, your son,' his father wired back, 'How sad, too bad, your dad,' and asked the New York fuzz to pick him up and bring him here. He was a typical meth monster until we switched him from meth to math. Next week he leaves to take a job as a computer programmer."

I was much impressed and promised Dr. Hawk and Mary Jane I wouldn't tip their identities until I got the word. Permission came near the end of December. The hippie movement was by then in such a shambles that the plastics, the part-time hippies from wealthy middle-class families, were no longer grooving. The hippies still hung up on the scene had parents who couldn't afford Squaresville's fee. Dr. Hawk sold the entire property to *Reader's Digest*. The 49 split-level homes are now filled with happy folk who commute daily between Squaresville and Pleasantville.

Rufus Isaacs' foxhole game, which readers were asked last month to solve, concerned a soldier who has a choice of hiding in one of five foxholes in a row and a gunner who has a choice of firing at one of four spots, *A, B, C, D,* between adjacent foxholes. An equivalent card game can be played with five cards, only one of which is an ace. One player puts the cards face down in a row. The other player picks two adjacent cards and wins if one of them is the ace.

"One can easily write a 4-by-5 matrix for this game and apply one of the general procedures described in the textbooks," Isaacs writes. "But, with a little experience, one learns in simple cases like this how to surmise the solution and then verify it."

The soldier's optimal mixed strategy is to hide only in holes 1, 3 and 5, selecting the hole with a probability of 1/3 for each. The gunner has a choice of any of an infinite number of optimal strategies. He assigns probabilities of 1/3 to *A*, 1/3 to *D*, and any pair of probabilities to *B* and *C* that add to 1/3. (For example, he could let *B* and *C* each have a probability of 1/6, or he could give one a probability of 1/3 and the other a probability of 0.)

In order to see that these strategies are optimal, consider first the soldier's probability of survival. If the gunner aims at *A*, the soldier has a 2/3 chance of escaping death. The same is true if the gunner aims at *D*. If he aims at *B*, he hits only if the soldier is in hole 3, so that again the probability of missing is 2/3. The same is true if he aims at *C*. Since each individual choice gives the soldier a 2/3 probability of survival, the probability remains 2/3 for any mixture of the gunner's choices. Thus the soldier's strategy ensures him a survival probability of at least 2/3.

Consider now the gunner's strategy. If the soldier is in hole 1, he has a hit

probability of 1/3. If the soldier is in hole 2, he is hit only if the gunner fires at A or B, and consequently the probability of a hit is 1/3 plus whatever probability the gunner assigned to B. If the soldier is in hole 3, he is hit only if the gunner fires at B or C, to which are assigned probabilities adding to 1/3. Therefore the probability of a hit here is 1/3. If the soldier is in hole 4, the probability of a hit is 1/3 plus the probability assigned to C. If he is in hole 5, the probability is 1/3. Thus the gunner's strategy guarantees him a probability of at least 1/3.

Assuming a payoff of 1 to the gunner if he kills the soldier, 0 if he doesn't, the value of the game is 1/3. The gunner has an infinite number of strategies that guarantee him a hit probability of at least 1/3. It is possible that he could do better against a stupid opponent, but against good opposition he can hope for no more because, as we have seen, the soldier has a strategy that keeps the probability of his death down to 1/3. A similar argument holds from the soldier's standpoint. By using his optimal strategy he keeps the payoff at 1/3 and cannot hope to do better because the gunner has a way of making it at least 1/3. As a further exercise, readers can try to prove that there are no optimal strategies other than those explained here.

"The process of surmising the solution is not as hard as it looks," Isaacs adds. "The reader can so convince himself by generalizing this solution to the same game but with n foxholes. For odd n the preceding solution carries over in an almost obvious way, but with even n one encounters some modest novelty."

If any readers made an empirical test of the optimal strategies of Isaacs' card-bluffing game, Guess It, along the lines suggested last month, I should be pleased to have a summary of the results.

In November a solution was published for the problem of placing 12 knights, the minimum possible, on a 10-by-10 chessboard so that all unoccupied cells are attacked. This solution was conjectured to be unique, but eight readers, first Jeffrey P. Golden, then Julian L. Ramsey, David L. Levin, Wade E. Philpott, Keith F. Avery, M. S. Riley, Paul D. Resler and Jean-Pierre Schwab found a second pattern [*see illustration on opposite page*]. For boards of sides 11, 12, 13, 14 and 15 the best solutions known are with 22, 24, 28, 34 and 37 knights respectively.

Because letters are still coming in on Lewis Carroll's double acrostic ballad given in September, I postpone comment on them until next month.

THE AMATEUR SCIENTIST

On equipment to study freezing and on growing crystals of salt

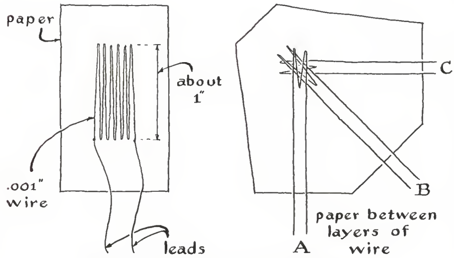
Conducted by C. L. Stong

Some interesting effects in nature are easily overlooked because they are so commonplace. Examples include the consequences of mixing salt with water or ice. In winter one sprinkles salt on highways and sidewalks to melt sleet and snow, but in summer one mixes salt and water to freeze ice cream! These seemingly contradictory effects—thawing and freezing—always occur simultaneously, but one of them is likely to escape notice if the other is the objective.

Simultaneous thawing and freezing can be demonstrated by a simple experiment that can be performed as a parlor trick. Float an ice cube in a glass of water. Have a shaker of salt within arm's reach. Hand someone a paper match and challenge him to remove the ice cube from the water without lifting it with any implement other than the match. When he gives up, bend the head of the match to a right angle, place the body of the match flat on top of the ice and cover it with a thin layer of salt. The match will promptly freeze to the cube. Lift the cube from the glass by the head of the match.

Inspection will disclose that the salt melted some ice all around the edge of the match. Ions of sodium and chlorine gained freedom of motion when they dissolved in the film of water on the surface of the cube, and motion was induced by heat drawn frcm the ice. Replacement energy then flowed from the region under the match that was protected from the salt. As a result the temperature of the film of fresh water in contact with the lower surface of the match dropped below its freezing point and turned into ice that cemented the cube to the match.

Common salt can similarly lower the temperature of water a degree or two, even in the absence of ice. Other salts are more effective. A good freezing solution can be made by dissolving in fresh water sodium thiosulfate (the photographer's "hypo"). The temperature of the solution can drop as much as 25 degrees Fahrenheit. To demonstrate the effect wet the bottom of a thin glass container with fresh water, stand the container on a base of wood or some other material that is a poor conductor of heat and fill the container with equal weights of water and hypo. Stir the mixture with a wooden stick for a minute or two. The wet bottom will freeze and the glass will stick to the base.



Simple strain gauge (left) *and rosette strain gauge* (right)

A stoppered vial of fresh water placed in the water-hypo solution will also freeze. If the vial is full, the expanding ice may exert enough pressure to break the glass, fresh water having the unusual property of being denser as a liquid than as a solid.

Recently Edward M. Little, who is a senior scientist with the Arctic Sciences Division of the Naval Undersea Warfare Center at San Diego, Calif., measured the pressure exerted by both freshwater ice and seawater ice. He found that the presence of salts in seawater reduced the pressure exerted by sea ice to a negligible amount, whereas freshwater ice developed pressures of more than 200 pounds per square inch. Little describes his work as follows:

"The structure of sea ice includes 'brine cells' that prevent high pressures from developing when the water solidifies. Sea ice is about as permeable to other substances as sandstone. (We are interested here in permeability, not porosity; a substance may be quite porous, but unless the holes in it are connected so that a liquid can flow through the material it is not permeable.) Sea ice turns out to be much more permeable than freshwater ice—probably at least 100 times more permeable.

"I made measurements of pressure by freezing water in a two-pound coffee can that was equipped with a strain gauge. A simple strain gauge consists of a wire .001 inch in diameter bent into a zigzag grid; the grid is cemented to bond paper and covered with felt for protection. The gauge is fitted with a pair of larger wires that serve as connections to the grid. Opposing forces applied to the sides of the gauge put the paper backing and the wires in tension. If the force is sufficiently large, the wire stretches and its electrical resistance increases. The increase in resistance is proportional to the strain, which is defined as a fractional increase in dimension, such as in length.

"Commercial strain gauges usually

include more than one wire grid. The commercial gauge I used is of the rosette type: two grids, separated by an insulator, are bonded to the paper backing at right angles to each other, and a third grid, similarly insulated and bonded, is set at an angle of 45 degrees to the other two [*see illustration on opposite page*]. I used only the two grids set at right angles to measure stresses in the can. The grids are labeled *A* and *C* in the illustration.

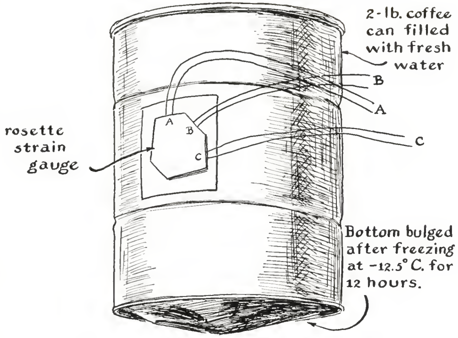
"The gauge was positioned so that the wires of grid *A* were parallel to the axis of the can. The wires of grid *C* extended in the direction of the can's circumference. The difference between the strains of the two grids provided a measure of the pressure in the can. The grids were connected in a circuit as opposite arms of a Wheatstone bridge. For this reason changes in resistance caused by variations of room temperature canceled each other, thus providing automatic temperature compensation. Grid *C* functioned as the active gauge, because it always had twice the strain of grid *A*.

"Strain gauges are often made of constantan wire, which consists of 60 percent copper and 40 percent nickel. The electrical resistance of constantan is relatively independent of changes in temperature. On the other hand, the resistance of constantan does change somewhat when the wire is stretched. The wire is said to have a 'gauge factor' of two. The phrase means that the percent change in the wire's electrical resistance corresponds to twice the percent change in length.

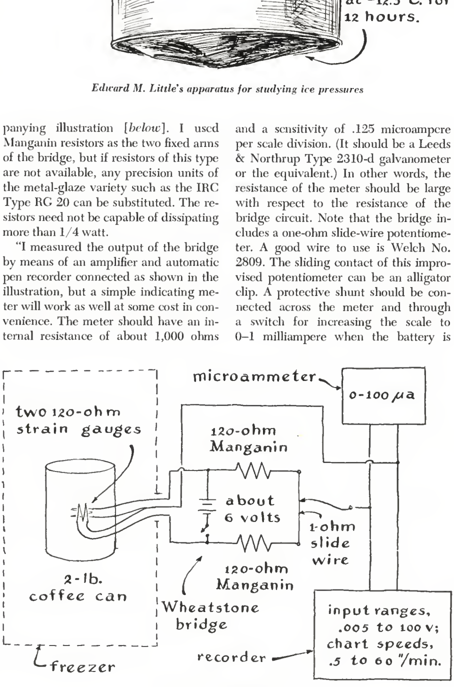
"Another popular material for strain gauges is isoelastic wire, an alloy of iron, nickel, chromium and other metals. It has a large temperature coefficient and a gauge factor of 3.5. I recommend that amateurs buy the Type AR-1 strain gauge for this experiment, because the substance to be studied must be cooled far below room temperature. The resistance of this gauge at room temperature is about 120 ohms; the gauge factor is two. The unit is manufactured by Baldwin BLH Electronics, Inc., 42 Fourth Avenue, Waltham, Mass. 02154, and is also available from distributors of scientific supplies.

"The can should be pre-bulged by freezing fresh water in it at less than 20 degrees centigrade. The circumference and thickness of the metal are then measured as accurately as possible. Bond the paper side of the strain gauge to the can with plastic cement and connect the leads into a Wheatstone bridge. The arrangement is depicted in the accompanying illustration [*below*]. I used Manganin resistors as the two fixed arms of the bridge, but if resistors of this type are not available, any precision units of the metal-glaze variety such as the IRC Type RG 20 can be substituted. The resistors need not be capable of dissipating more than 1/4 watt.

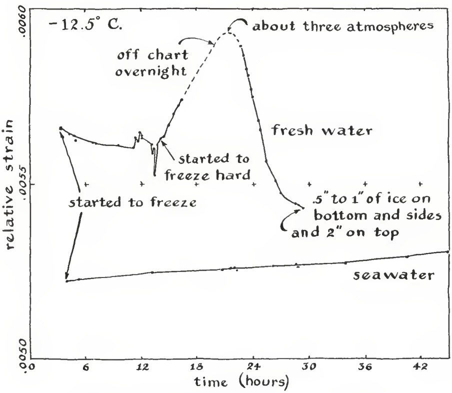
"I measured the output of the bridge by means of an amplifier and automatic pen recorder connected as shown in the illustration, but a simple indicating meter will work as well at some cost in convenience. The meter should have an internal resistance of about 1,000 ohms and a sensitivity of .125 microampere per scale division. (It should be a Leeds & Northrup Type 2310-d galvanometer or the equivalent.) In other words, the resistance of the meter should be large with respect to the resistance of the bridge circuit. Note that the bridge includes a one-ohm slide-wire potentiometer. A good wire to use is Welch No. 2809. The sliding contact of this improvised potentiometer can be an alligator clip. A protective shunt should be connected across the meter and through a switch for increasing the scale to 0–1 milliampere when the battery is



Edward M. Little's apparatus for studying ice pressures



Circuitry of the strain gauge



Graph of strain induced by freezing at —12.5 degrees centigrade

switched on and the bridge is unbalanced.

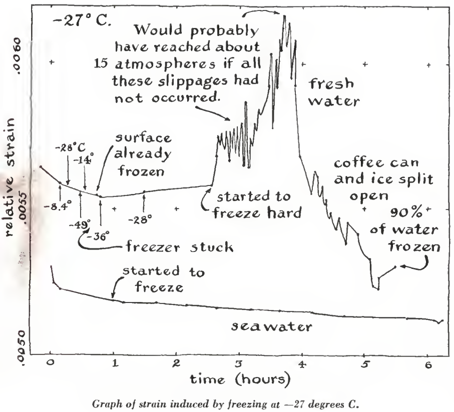
"To measure the pressure exerted by ice, fill the can with water to within an inch of the top, connect the gauge to the bridge circuit, balance the bridge with the one-ohm potentiometer so that the meter reads 0, place the can in the freezer and close the battery switch. Make a table of two columns, one for time and the other for meter readings. Readings should be taken at regular intervals. At a freezing temperature of -12.5 degrees C. a complete test run will take two full days; at -27 degrees the run will last about six hours.

"All that remains is to calibrate the meter in terms of pressure, a simple calculation that takes into account the size of the can, the elasticity of the metal and the voltage of the battery that energizes the bridge. The current I_g that is indicated by the meter in microamperes is equal to the excess pressure p developed in the can, multiplied by the radius r of the can in centimeters and by the battery voltage V_b, divided by twice the elasticity E of the metal of which the can is made, multiplied by the thickness of the metal t in centimeters and by the internal electrical resistance of the meter R_g. The result is equal to the pressure (in atmospheres) per microampere of current, as indicated by the meter. Expressed symbolically, the relation is $I_g = prV_b/(2EtR_g)$.

"The can I used was 12.4 centimeters in diameter, so that its radius was 6.2 centimeters. The thickness of the metal was .0109 inch, or .0277 centimeter. A reasonable value for the elasticity of steel of the kind used in most tin cans is about 2×10^{12} dynes per square centimeter. I used a six-volt battery. One atmosphere of excess pressure in the can is equal to 10^6 dynes per square centimeter. The internal resistance of my meter is 1,000 ohms. The calibration is completed by substituting these quantities for the symbols in the formula and doing the arithmetic: $I_g = 10^6 \times 6.2 \times 6/(2 \times 2 \times 10^{12} \times .0277 \times 1{,}000) = 3.3 \times 10^{-7}$ amperes, or .33 microampere per atmosphere of pressure. Apparatus that differs in size from my setup can be similarly calibrated by substituting appropriate quantities in the formula.

"Although an indicating meter is adequate for the experiments, I used an automatic pen recorder as a convenience. The instrument was calibrated in terms of relative strain instead of pressure. Six microamperes indicated a strain of .001 inch per inch, or .1 percent. Relative strain was plotted against time for each of two experiments, one run at a freezing temperature of -12.5 degrees C. and the other at -27 degrees. Pressure corresponding to the indicated strain was then calculated.

"When making the graphs, I subtracted .0003 from the strain readings of the two sea-ice recordings so that the plots for freshwater ice and seawater ice would not overlap. The strain gauge used for the experiment at -12.5 degrees C. had a gauge factor of 3.5. The output of the gauge drove the pen of the recorder off scale. The instrument in-

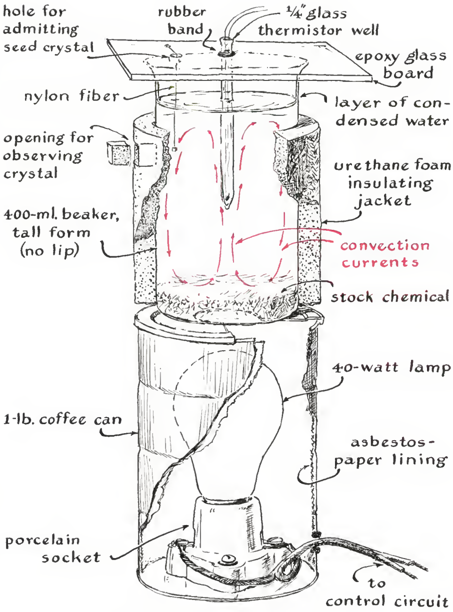


Graph of strain induced by freezing at —27 degrees C.

cluded a compensating dial that I set at 2. The setting in effect multiplied the output by 2/3.5, or a factor of .58. The relative increase in strain due to the freezing of fresh water at −12.5 degrees C. turned out to be .00593 − .0056, or .00033, which is .033 percent. In the case of this experiment p equals 1.787 times 10^{10} times .58, or 3.41×10^{6} dynes per square centimeter, which is equivalent to about three atmospheres [*see top illustration on opposite page*].

"I was puzzled at first by the graph of freshwater ice frozen at −27 degrees C. [*see bottom illustration on opposite page*]. It has many sharp peaks that indicate abrupt changes in pressure. The explanation became clear when the ice was melted from the can. The soldered joint along the seam of the can had been torn apart. Evidently when the solder was stressed by the expanding ice, it gave way in a series of breaks. It is possible to estimate the maximum pressure that would have developed in an unyielding can by adding the individual peaks of the graph. The sum indicates a maximum pressure of about 15 atmospheres, or 235 pounds per square inch.

"In spite of the experimental uncertainty, the graphs show clearly that seawater does not behave like fresh water when it freezes. The difference stems mainly from the higher permeability of seawater ice. Incidentally, chilled seawater in sealed cans makes an effective and convenient refrigerant for preserving foods in picnic ice chests. The leftover seawater surges harmlessly through the already frozen sea ice instead of distorting the containers. To provide room for the expansion the cans should not be filled to more than 80 percent of their capacity."



James Bailey's apparatus for growing crystals

James Bailey of Milwaukee also experiments with saline fluids, but instead of crystallizing water by freezing he applies controlled heat to the solution for growing large single crystals of the salt. Bailey writes:

"Generations of amateurs have made a hobby of growing large single crystals of various salts such as copper sulfate, alum, hypo and similar chemicals. Traditionally two techniques have been used. One involves cooling, the other evaporation.

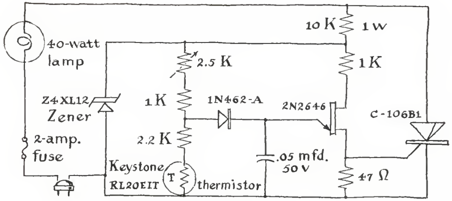
"Both begin with the preparation of a saturated solution. Salt is mixed with water until no more will dissolve. The solution is filtered, preferably through a sheet of permeable paper made specially for the purpose. Filtering removes minute crystals that could otherwise remain in solution and grow at the expense of the desired single crystal.

"A single crystal is always grown on a seed of some kind—a speck of foreign matter, a minute crystal of the salt or even a cluster of molecules. The seed is suspended by a thread and lowered into a bath of distilled water for a few seconds, just long enough to dissolve any microscopic crystals that may have collected on its surface. It is then transferred to the filtered solution. The concentration of the filtered solution is increased by either cooling or evaporation. When the temperature of a saturated solution is thus lowered, the water becomes supersaturated. Excess salt must leave the solution and reappear in the form of one or more crystals.

"To grow crystals by the cooling technique the saturated solution can be made at a temperature higher than the room temperature. A prepared seed is lowered into the bath and the heat is slowly reduced. Alternatively the cooling can be achieved by putting a room-temperature solution in a refrigerator.

"Supersaturation can also be induced by letting the water evaporate. The technique is slow but popular because of its simplicity. Weeks or even months may be required to grow large single crystals by evaporation, depending on the nature of the salt. During this interval the solution may be contaminated accidentally by foreign particles from the air or other sources.

"I have been experimenting with a third technique, known as the hydrothermal process. It provides positive control over the rate of crystal growth and protects the solution from dust and



Circuitry of the automatic temperature-control device

other airborne contamination. Manufacturers have used the method extensively in recent years to grow crystals of quartz. The equipment consists of a source of heat, an insulated vessel that holds the solution, an excess of the chemical to be crystallized and a thermostat for maintaining the solution at a constant average temperature.

"If the apparatus is operated in a room that is maintained at about 70 degrees F., heat must be provided to the solution at the rate of about 80 watts per liter. An introductory apparatus can consist of a 400-milliliter beaker heated by a 40-watt incandescent lamp [*see illustration on preceding page*]. The beaker must be wrapped with a sheet of urethane foam (or an equivalent insulating material) that covers 90 percent of the solution. The top of the beaker can be closed by a sheet of transparent plastic that contains two holes—one for admitting the seed crystal to the solution and the other for supporting a glass-enclosed thermistor (Keystone RL 20 EIT, Keystone Carbon Co., Thermistor Division, St. Marys, Pa. 15857, or equivalent). Do not use a vessel of thick glass that might break when heated.

"The thermistor acts as a temperature-sensitive resistor in a circuit that automatically adjusts the power to the incandescent lamp as necessary to maintain the solution at a constant average temperature. A Zener diode applies a constant voltage to a string of resistors that includes the thermistor. The voltage that appears across the thermistor and the 2,200-ohm fixed resistor of the string varies with the temperature of the solution. This voltage is applied to the emitter of a unijunction transistor, which in turn energizes the gate electrode of a silicon-controlled rectifier. The silicon-controlled rectifier functions as a throttle for applying power to the incandescent lamp.

"When the temperature of the solution, as sensed by the thermistor, increases or decreases beyond predetermined limits, the silicon-controlled diode adjusts the energy of the lamp just enough to compensate for the change, thereby maintaining the solution at a constant temperature. Conversely, above a predetermined temperature the silicon-controlled rectifier switches the lamp off. The temperature limits within which the lamp is thus controlled can be raised or lowered by adjusting the 2,500-ohm rheostat connected in series with the thermistor.

"The C-106B1 silicon-controlled rectifier is designed for a maximum current of two amperes and will switch incandescent lamps rated up to 150 watts. When lamps larger than 40 watts are used, a two-watt resistor of 10,000 ohms should be substituted for the one-watt unit specified in the accompanying illustration [*above*]. All other resistors are rated at one watt.

"Silicon-controlled rectifiers of any type can be substituted for the specified unit if more or less switching capacity is desired. The silicon-controlled rectifier must be equipped with a metal heat sink. The heat sink operates at the potential of the power line and must therefore be enclosed by and insulated from a housing. The components of my unit were assembled in a small plastic box.

"The insulated beaker is heated by a hot plate. I use an inverted coffee can, with a hole in the bottom, that houses the lamp bulb and socket. When setting up the apparatus, I usually prepare the concentrated solution in a separate vessel at a temperature of about 110 degrees F., slightly above the growing temperature. A layer of salt about one centimeter thick is placed in the growing vessel. The saturated solution is filtered on top of the chemical. The growing vessel is placed on the hot plate and covered. The warmed solution rises by convection and cools as it streams upward and returns along the walls of the container.

"During the excursion the solution reaches saturation as it approaches the top of the vessel and becomes supersaturated at some point during its return along the walls. The seed crystal is suspended for growth in the region of supersaturation, which must be located by experiment. I usually apply heat to freshly prepared solutions for about five hours before introducing the seed crystal. During this interval the circulation and the region of supersaturation become stable.

"A thin layer of fresh water also forms on the surface as the result of condensation that collects on the lower surface of the cover and drips back into the container. This layer is useful because it dissolves from the seed any microscopic crystals that may have formed after the seed was cleaned. I use nylon thread for suspending seed crystals.

"When possible, I buy salts in crystalline form and select the most perfectly formed crystals for use as seeds. This is a painstaking operation that often requires the use of a magnifying glass. Some salts are sold in powdered form. These are dissolved and crystallized by evaporation. Seeds are then selected from the resulting mass of small crystals.

"A perfectly formed crystal for use as a seed can be grown by suspending any fragment of a broken crystal in a concentrated solution of the salt. Use a thread to suspend the crystal. The container must be airtight and must also be maintained at a constant temperature to prevent any change in the concentration of the solution. The conversion of the fragment into a perfect crystal may require days or weeks, depending on the nature of the salt.

"Harvesting mature crystals is easy. They are simply pulled from the growing solution and wiped dry with a soft cloth. Some crystals are sensitive to abrupt changes in temperature and may crack if they are pulled from the warm bath when the air in the room is abnormally cold. They can be harvested safely by first cooling the solution to room temperature. Incidentally, I have been trying without much success to grow large crystals of calcium carbonate and should appreciate any tips that fellow enthusiasts might pass along. Indeed, I should be happy to exchange information on any aspect of the hobby. My address is 5606 South 34th Street, Milwaukee, Wis. 53221."

BOOKS

Mathematics, the childhood of Isaac Newton's science

by I. Bernard Cohen

THE MATHEMATICAL PAPERS OF ISAAC NEWTON, VOLUME I: 1664–1666. Edited by D. T. Whiteside. Cambridge University Press ($40).

The inaugural volume of D. T. Whiteside's monumental edition of *The Mathematical Papers of Isaac Newton* (to be completed in eight volumes) deals with only three years in Newton's life: 1664–1666. But what golden years they were! In them Newton was first exposed to higher mathematics and firmly launched on his almost legendary scientific career. Guided by Whiteside's sure hand, we can now study Newton's early mathematical notes and first mathematical essays. We thus become privileged witnesses to the actual formation of one of the keenest minds of all time.

The basic task of editing Newton's mathematical papers is to place them in chronological order and transcribe them, but the editor must have the mathematical training and insight needed to understand and interpret them. Happily Whiteside brings to this assignment a rare combination of mathematical and linguistic ability and an abiding sense of history. He has had not only the patience to steep himself in the mathematical thought of another age but also the wit to discern the significance of each document in the light of Newton's development and currents of knowledge in the 17th century.

In this edition each document follows the form of the original as closely as type allows, and Whiteside has been careful to keep separate his critical emendations and Newton's own formulations. Copious notes form a continuous commentary to help the reader follow Newton's mathematical argument, which is often extremely difficult for the uninitiated modern reader. These notes, and the introductions to the several sections, constitute the best account in print of the main features of 17th-century mathematical thought and so go far beyond the major assignment of illuminating Newton's mathematical development.

Whiteside has spent 10 years studying the printed and manuscript sources, and he is already known to scholars for his earlier monograph *Patterns of Mathematical Thought in the Later Seventeenth Century*. With the publication of the Newton volume, with its riches of new and unexpected material and original interpretation, he has raised Newtonian scholarship to a new plane. It is difficult to think of any other work in recent years that surpasses it in importance in the entire field of the history of science. It profoundly illuminates the creative process of science in a manner completely worthy of its subject.

Newton, thrice great like the magical patron of alchemy Hermes Trismegistus, dominated the rise of three major sciences in modern times: rational mechanics, experimental optics and pure mathematics. Known in his day for achievements unsurpassed by any predecessor or contemporary, he had penetrated the mysteries of light and color (and had invented a new type of telescope), had found the law of universal gravitation (thus to explain at once why the planets move around the sun in accord with Kepler's three laws and why stones fall to earth as Galileo had found they do) and was an inventor of the "fluxional calculus," the new language of the exact sciences. With the kind of admiration usually granted to superheroes in war or athletics, Newton's contemporaries asked whether he was at all like ordinary men: did he eat and sleep like other mortals? They even compared him to the Nile (whose source had not yet been found), speculating that Newton was revealed to us only in the full stream of his mighty intellect—the source or sources being permanently hidden from our view.

What is it that makes a mind so creative that we still contemplate its achievement with awe some 300 years later? We cannot really say much more on this subject today than men of true insight in Newton's time could. We do have one advantage over our predecessors: thanks to the heroic labors of Whiteside we can see for ourselves the sources from which Newton's mathematical achievement sprang.

Newton's yeoman ancestors showed no special talent for science or mathematics. For that matter, Newton's early years of training and education are singularly lacking (for one who became so great) in auguries of a hidden genius straining to break the confines of its environment. Born on Christmas Day in 1642 (in the Julian calendar), Newton was educated in local country schools and the grammar school at Grantham in Lincolnshire. Like others in his time he learned Latin and Greek and eventually acquired enough Hebrew to write out texts in it. He must certainly have become acquainted with elementary arithmetic: addition, subtraction, multiplication, division, the reduction of fractions and the use of proportions. He does not seem to have read much, if anything, that could properly be called scientific. He did pay rather close attention to John Bate's *Mysteries of Nature and Art*, from which he got the idea of making water clocks, toy mills and other mechanical devices. Like many other scientists then and now he was a true gadgeteer, and he appears to have shown a certain proficiency in drawing. These talents must have stood him in good stead in later years, when he made his own telescopes (including grinding the mirrors) and the apparatus he needed for his experiments.

In 1947, when the old Newton homestead in Woolsthorpe was being renovated, a number of drawings and diagrams were uncovered, some carved into the stone and others scratched into the plaster. I can only agree with Whiteside's judgment: "It would need the blindness of maternal love to read into these sets of intersecting circles and scrawled line-figures either burgeoning artistic prowess or mathematical precocity."

When Newton went down to Cambridge from Lincolnshire, he had as yet shown no sign of the massive talent that was to change the world. A poor and

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design an oil refinery.

rather young student, evidently shy and not gifted at making friends, he was in no way remarkable or worthy of notice from his contemporaries. Many notebooks survive from those undergraduate years to tell us in detail about his studies. We can turn the pages of notes in Greek on Aristotle's *Analytics* and *Ethics,* and then read comments in Latin taken from various 17th-century Aristotelians. We can see how the young Newton progressed from the customary topics of logic, rhetoric and ethics to physics; not yet the physics of his own time but the *Physics* of Aristotle, interpreted by the late-16th-century scholastic Johannes Magirus. Two extracts presented by Whiteside show the strongly scholastic or medieval quality of Newton's mathematical thinking at the time:

"Extension is related to places, as time to days. yeares &c. Place is y^e principium individuationis of streight lines & of equall & like figures...."

"If Extension is indefinite onely in greatness & not infinite y^n [then] a point is but indefinitely little & yet we cannot comprehend any thing lesse. To say y^t [that] extension is but indefinite... because we cannot perceive its limits, is as much as to say God is but indefinitely perfect because wee cannot apprehend his whole perfection."

So far all is traditional. Then, at the beginning of Newton's final year as an undergraduate (1664), his notebooks give us two very different signs. First of all, as Whiteside explains, Newton abruptly changed "his early, rather ornate handwriting for the simpler, less pretentious form which was to remain his throughout the rest of his life." Second, he gave up an exclusive diet of reading the ancients and their commentators and plunged into the moderns. From this year onward we can trace the genesis and flowering of Newton's genius as he came to know the scientific writings of the men of his own century. From them he took whatever tools or methods or concepts he could use in forging his own, and soon we see him exercising his newly acquired powers to produce a novel Newtonian science and Newtonian mathematics and to surpass one by one those who had been his mentors. It is for this reason that the documents that are printed in the first volume of Whiteside's edition are so precious; they come from those crucial years 1664–1666, when Newton first developed his mathematical prowess.

Newton's notebooks show us at close range how he learned the "new science." Among the major authors he read were Walter Charleton, an expert on ancient and modern atomism and on the physics of Galileo and Pierre Gassendi, and Kenelm Digby, whose presentation included the physics and philosophy of Descartes along with the ideas of Galileo. Newton also read philosophical and scientific writings by Joseph Glanville, Thomas Hobbes and Henry More, and he devoured books by Robert Boyle and Robert Hooke. He took careful notes on his reading in the *Philosophical Transactions* of the young Royal Society of London. He also read and made notes on Galileo's *Dialogues on the Two Great Systems of the World* and Descartes's *Principles of Philosophy;* from Descartes he copied out an English version of the principle of inertia, which was later to become Newton's first law of motion. As we turn the pages of his notebooks we can see his mind leap from summaries of his reading to his own new principles and results. An outstanding example is his formulating the law of "centrifugal force" (that the force when a body moves uniformly along a circle is at once directly proportional to the square of the speed and inversely proportional to the radius) years before it was published by Christiaan Huygens, who is usually credited with the discovery. He also began to think of gravity as a force extending as far as the moon.

In mathematics as in physics and astronomy Newton turned to the new authors of his century. According to the mathematician Abraham De Moivre, who knew him well, Newton's introduction to higher mathematics (higher, that is, than the simple arithmetic he knew on entering college) began when he "bought a book of Astrology" in 1663 "out of a curiosity to see what there was in it." He found he could not understand "a figure of the heavens" for "want of being acquainted with Trigonometry." He therefore got himself a book of trigonometry "but was not able to understand the Demonstrations," and so he got "Euclid to fit himself for understanding the ground of Trigonometry." De Moivre then records the following about Newton: "Read only the titles of the propositions, which he found so easy to understand that he wondered how any body would amuse themselves to write any demonstrations of them. Began to change his mind when he read that Parallelograms upon the same base & between the same Parallels are equal, & that other proposition that in a right angled Triangle the square of the Hypothenuse is equal to the squares of the two other sides."

De Moivre continues: "Began to read Euclid with more attention than he had done before & went through it." Next Newton read William Oughtred's *Clavis.* Then:

"Took Descartes's Geometry in hand, tho he had been told it would be very difficult, read some ten pages in it, then stopt, began again, went a little farther than the first time, stopt again, went back again to the beginning, read on till by degrees he made himself master of the whole, to that degree that he understood Descartes's Geometry better than he had done Euclid.

"Read Euclid again & then Descartes's Geometry for a second time. Read next Dr. [John] Wallis's Arithmetica Infinitorum, &... found that admirable Theorem for raising a Binomial to a power given...."

The last statement is a reference to one of the best known of Newton's early mathematical discoveries, the series expansion of a binomial to any power n, that is, $(1 + a)^n$.

Whiteside shows that De Moivre's story conforms to the evidence of Newton's notebooks and certain books from Newton's library, happily preserved at Trinity College, Cambridge. Among these books Whiteside finds a "well-thumbed and marginally annotated copy of Euclid's *Elements* (in Barrow's 1655 edition)," which bears witness to Newton's examination of this work. As for Descartes's *Géométrie,* Whiteside tells us that Newton did not read it in the original French but in the second Latin edition of 1659–1661, and that he studied not only Descartes's original text but also an extensive commentary by Frans van Schooten. In support of De Moivre's account Whiteside also adduces testimony from Newton himself, in the form of certain autobiographical notes:

"July 4th 1699. By consulting an accompt of my expenses at Cambridge in the years 1663 & 1664 I find that in y^e year 1664 a little before Christmas I being then senior Sophister [an undergraduate] I bought Schooten's Miscellanies & Cartes's Geometry (having read this Geometry & Oughtreds Clavis above half a year before) & borrowed Wallis's works and by consequence made these Annotations out of Schooten & Wallis in [the] winter between the years 1664 & 1665. At w^ch [which] time I found the method of Infinite series. And in summer 1665 being forced from Cambridge by the Plague I computed y^e area of y^e Hyperbola at Boothby in Lincolnshire to two & fifty figures by the same method."

From these beginnings in 1664, in Whiteside's judgment, "Newton over the next two years (and not only of course in mathematics) was to develop a re-

markable series of researches formidable in technical content and effervescent with still untested creative thoughts.... Their detailed systematization, carried through by a typically stubborn perseverance and massive power of mental concentration, was to take most of the rest of his life."

Assembling Newton's mathematical papers and putting them in chronological order was in itself a formidable task. Although the bulk of the manuscripts is in Cambridge (primarily in the University Library but also in the libraries of Trinity College and King's College), other documents are scattered far and wide. The original order in which Newton had arranged his manuscripts had been violated by later librarians and cataloguers. Scraps and fragments had to be identified, some of them belonging to the same document but differing in style or physical appearance because they were earlier or later versions or states. Dating the documents was altogether a vexing problem. In some cases a date could be assigned on internal evidence or by an ancillary autobiographical document, but in the end Whiteside became so steeped in Newton's written words that he could in most cases date documents closely by the form of the handwriting, which varied slightly from year to year. I can speak from personal experience in saying that dates Whiteside has assigned in this way have repeatedly been confirmed by independent evidence.

Whiteside received very little help from earlier works; only a few of the documents in his collection had been published before. Although this situation has been acute with respect to Newton's mathematical work, it applies in Newtonian scholarship generally. In spite of the fact that the bulk of Newton's scientific manuscripts have been available for almost a century, little use has been made of them by scholars, who have largely based their studies of Newton on published material rather than on manuscripts. In recent years, however, the situation has been changing as it has become increasingly clear that a full comprehension of the development of Newton's thought requires close study of all his writings. Among those who have now intensively mined the manuscript archives are the late Herbert W. Turnbull (the editor of Newton's *Correspondence*) and J. F. Scott (the current editor), the late Alexandre Koyré, A. Rupert Hall and Marie Boas Hall, John Herivel, Joseph Lohne, J. E. McGuire, R. S. Westfall and myself.

In his first volume Whiteside presents Newton's texts in three groups: the first mathematical annotations (1664–1665), from Oughtred, Descartes, Schooten and Huygens; then Newton's manuscript records of his research in analytic geometry and calculus (1664–1666), and finally some miscellaneous early researches (1664–1666). From the evidence presented there can be little doubt of the correctness of Whiteside's judgment that "beyond reasonable doubt" Newton was "self-taught in mathematics, deriving his factual knowledge from the books he bought or borrowed, with little or no outside help." There appears to be no ground whatever for the "pleasant story of [Isaac] Barrow's tutorial guidance," which is enshrined in one of Walter Savage Landor's *Imaginary Conversations.*

Newton's notes, observes Whiteside, "are not mere inferior, copied images but have their own life, revealing a young mathematician at work stretching his mind, shaping what he read and recording his own impressions." At times it is difficult to draw a hard and fast line between the end of a summary and "the following wave of new ideas" as it becomes "a piece of original research." The transformation of a youth who knew no more mathematics than simple arithmetic, and who could not read a treatise on astrology for want of trigonometry, into a profound creator of higher mathematics is marvelous to follow. The first annotation presented, taken from a small notebook in which Newton had begun to make a Hebrew-English dictionary, lists the properties "of right angled triangles," or the Pythagorean theorem, in answer to the problem, "Any two leggs given to find y^e other." The solution is given in three equations, with a reference to Euclid's "lib. 1. pr: 47":

1. $bq + cq = hq.$
2. $r{:}hq - bq{:} = c.$
3. $r{:}hq - cq[{:}] = b.$

In these equations q stands for *quadratus*, or "squared," so that the first equation merely states that the sum of the squares of the two sides b and c equals the square of the hypotenuse h. In the second and third equations c is given in terms of the root (r) of $h^2 - b^2$ and b in terms of the root of $h^2 - c^2$. Newton has gone beyond addition and multiplication, but not too far. Before long, however, he is deep in the geometry of conic sections. Then he becomes fascinated by the problems of permutations and combinations, for example, the number of conjunctions that can be made of the seven planets, taken in any combination. He concludes that the "7 Planets may be conjoyned 120 divers ways," mistakenly copying 120 for 127. He also finds that "$1 \times 2 \times 3 \times 4 \times 5 \times 6. = 720.$ are y^e number of changes [that can be rung] in six bells." This is 1664, but before long he has gone deeply into number theory and algebra and shows himself to have mastered "the arithmetical symbolisms from Oughtred" and the "algebraical from Descartes." This was the basis of his own symbolism, with many modifications and innovations added.

The rise of Newton as a mathematician can be seen most clearly in his notes on the writings of John Wallis. Here we find him gaining an acquaintance with the theory of "indivisibles" (an immediate precursor of the calculus) and acquiring from Wallis a sure grasp of the methods of infinite series and continued products. By 1665 he had thus advanced from the algebra of Cartesian geometry and from simple number theory to the realm of higher mathematics, even as we still understand the expression. For instance, we find Newton using at this stage a logarithmic series for log $(1 + x)$ to "square the Hyperbola," that is, to find the area of a segment:

$$``x - \frac{x^2}{2} + \frac{x^3}{3} - \frac{x^4}{4} + \frac{x^5}{5} - \frac{x^6}{6} + \frac{x^7}{7} - \frac{x^6}{[8]} + \frac{x^9}{9} - \frac{x^{10}}{10}.\ \&c."$$

He calculated the value for x as $1/10$, but Whiteside finds his results in part "vitiated by two small numerical slips, one of addition and one of subtraction." So much for those who would believe Newton was a marvelous calculator! To judge by a number of different manuscripts, Newton was particularly fascinated by the problem of determining the areas of hyperbolas, and it was in the course of investigating this topic that he found the general binomial expansion theorem.

On the basis of his study of the manuscripts Whiteside observes: "Already by mid-1665, one short crowded year after his first beginnings, the urge to learn from the work of others was largely abated. The indication of his rapid rise to mathematical maturity is telling. It was time for him to go his own way in earnest and thereafter, though he continued to draw in detail on the ideas of others, Newton took his real inspiration from the workings of his own fertile mind." This is amply confirmed by the documents—short essays or tracts rather than annotations—that contain "the written record of his first researches in the interlocking structures of Cartesian coordinate geometry and infinitesimal analysis," which comprise the second part of this volume, accounting for more than half of the whole.

It is on these papers on analytical

Nancy and John Seletti aren't trying to save the world. Just a little piece of it.

About a mile outside the Korean village of Ku Am there are a few dozen young, still-tender mulberry trees growing on a small hill. Someday these trees and their succulent leaves will be the heart of a new village industry—a silk raising farm. That day is still many months off, but it doesn't stop the village men from making daily inspection treks up the steep hill, just in case. Just in case something miraculous has happened since yesterday. After all, it wouldn't be the first miracle to happen in Ku Am. Everyone in the village knows the story of Chang Sook, the daughter of the widow.

Ten years ago Chang Sook's chances of survival were as slim as she was. Her father had disappeared during the family's flight from North Korea. Her mother, a seamstress, worked a backbreaking day and most of the evening to earn $10 a month. Barely enough to keep them from starving.

But today that's all changed because an American couple named Seletti are sharing a little of their good fortune with a girl to whom a little means everything. Nancy, John and five-year-old Alexandra Seletti are New Yorkers. They're not fabulously wealthy as the villagers of Ku Am believe. But, they're not poor either. *Comfortable* probably describes them best. They have everything they really need, but give them ten minutes and they'll come up with ten things they want that $15 a month would buy. Luckily, they thought of Chang Sook first.

Through Save the Children Federation, the Seletti's $15 a month is doing a remarkable number of things. First, Chang Sook's immediate needs and future schooling are being taken care of. The family is getting help, too: Enough to enable Chang Sook's mother to start a small knit shop.

And with all this, there is still some money left over. This money, together with money from other sponsors, was borrowed by the village to start its precious mulberry farm. Someday silk raising will mean a permanent increase in the village's income—and permanently end the need for charity. That's what Save the Children Federation is all about. Although contributions are tax-deductible, it is not a charity. The aim is not merely to buy one child a warm coat, a new pair of shoes and a six month supply of vitamin pills. Instead, your contribution is used to give the child, the family and the village a little boost that may be all they need to start helping themselves.

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5420. Windy, Release Me, Happy Together, Somethin' Stupid, Mary In The Morning, etc.

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*Records marked with a star have been electronically rechanneled for stere

geometry and calculus, Whiteside concludes, that "Newton laid the foundations of his mature work in mathematics, revealing for the first time the true magnitude of his genius." Whiteside then presents an admirable summary of Newton's meditations and analyses, which deserves to be reproduced here:

"As in so many other fields—and though we should not underestimate the impact of Wallis' work upon him—in the creation of his calculus of fluxions Newton's chief mentor was Descartes. From the latter's *Geometrie*, a veritable mathematical bible in Schooten's richly annotated second Latin edition, he drew a continuous inspiration over the two years from the summer of 1664. Beginning with the Cartesian technique for constructing the subnormal to an algebraic curve, Newton swiftly soaked up the algorithmic facility of Hudde's rule *de maximis et minimis* but quickly came to appreciate its hidden riches, applying it to the construction of the subtangent and of the circle of curvature at a general point on an algebraic curve and ultimately formulating a differentiation procedure founded on the concept of an indefinitely small, vanishing increment. On that basis and little afterwards he was able to set down the standard differential algorithms in the generality with which they were to be expounded by Leibniz two decades later. Along with this a parallel stream of researches, built on Wallis' work in the theory of the algebraic integral and on Heuraet's general rectification procedure, culminated about the same time (mid-1665) in a limited mastery of the quadrature problem and in geometrical insight into the inverse problem of tangents. In the summer and early autumn of that year, away from books in Lincolnshire and with time for unhurried thought, Newton recast the theoretical basis of his new-found calculus techniques, rejecting the concept of the indefinitely small increment in favour of that of the fluxion, a finite instantaneous speed defined with regard to an independent dimension of time and on the geometrical model of the line-segment. Soon after, in the autumn of 1665, he was led to restudy the tangent-problem by the Robervallian method of combining limit-motions of a point defined in a suitable co-ordinate-system. After an initial crisis in his construction of the quadratrix-tangent he was able correctly to generalize the method, giving in May 1666 a comprehensive treatment of tangents by limit-motion analysis and extending its area of application to include the construction of inflexion points. In the autumn of 1666, lastly, and as a not unintended finale, almost all these researches were ordered and condensed in a short, unfinished and till recently unpublished work to which he gave no title but which, following his own practice in later reference, we may name the 'October 1666' tract.

"In those two years a mathematician was born: a man, certainly, still capable of profound error but with a depth of mathematical genius which by late 1666 had made him the peer of Huygens and James Gregory and probably the superior of his other contemporaries. His only earnest regret must have been that he had yet found no outlet for communicating his achievement to others. The papers printed in the following pages throb with energy and imagination but yet convey the claustrophobic air of a man completely wrapped up in himself, whose only real contact with the external world was through his books. That was to change somewhat in years to come, but it was Newton's continuing tragedy that he was never to find a collaborator of his own mental stature."

One final observation can be made. In the papers presented by Whiteside, Newton shows himself to have been extraordinarily fertile in the invention of mathematical symbols as they were needed. In dealing with the problems of tangents and of curvature he introduced a kind of dot notation for partial differentiation but not for ordinary differentiation. This is surprising because Newton's fluxional calculus is generally known for the use of "pricked," or dotted, letters for ordinary differentials, for example $\dot{x}$ for dx/dt and $\ddot{x}$ for d^2x/dt^2. He also employed a small square to indicate integration. The most interesting symbol is a kind of script X he seems to have devised around 1666 for a general algebraic function of two variables $f(x,y)$. Then, by placing one or more dots to the left or right, he could indicate xf_x, yf_y, x^2f_{xx}, xyf_{xy} or y^2f_{yy}. Whiteside finds, however, that he did not invent dotted letters for ordinary differentials until 1691, which provides an answer for those who are puzzled because he did not use his dotted letters in the *Principia*. It was published in 1687.

Short Reviews

HIGH FREQUENCY COMMUNICATIONS, by J. A. Betts. American Elsevier Publishing Company Inc. ($5). The whispering gallery that the ionosphere makes of our earth is full of sounds. At wavelengths between 10 and 100 meters a short-wave receiver can pick up not only broadcasts in a dozen tongues, and

not only the intermittent fluting of the old-fashioned dot-dash radio telegraphy, but also a wide variety of drones, buzzes, mad piccolo choruses and random bagpipe quartets. All these strange and purposeful signals are the modern radio engineer's answer to the increasing pressure for the transfer of point-to-point messages, both by written characters and by voice. The number of terminals all over the world seeking to communicate through the fickle and shifting channels that bend and bounce radio signals around the earth is now counted in the thousands. Cables are doubtless surer, quieter and more private, but they are costly. Wires cannot be strung directly between Mozambique and Montevideo, and the use of a relaying network via Cairo, London and New York will always be irksome, slow and uncertain. But buy a small houseful of the right equipment, set up a few tall poles over some acres of land, file an arrangement with the international agencies in Geneva for the allocation of channels and for payments, and Mozambique or anywhere else is in touch with the world. It is the spread of activity over a hundred nations that has loaded the ionosphere with traffic like a Los Angeles freeway. Ships and planes, of course, make their own growing demands.

This short and simply written book, filled with technical detail (at the level of block diagrams rather than circuits), replete with graphs and performance data, introduces the reader to how radio engineers have managed their traffic jam. It is a story of ingenuity and rationality at every point. Since the war years they have exploited ionosphere soundings in order to know and to predict the optimal channels, shifting with the sun and the sunspots, for each route and hour. Given that knowledge, they have put in clever schemes of error-correction, so that they can work even under marginal conditions, saving precious hours of channel. The system used most often nowadays is a redundant code, arranged so that the receiver can detect a discrepancy and automatically ask for a repeat by injecting a code group among the normal messages that flow along the return channel. Precise frequency definition, and yet quick frequency shifts, are needed for full use of the ionosphere. They are guaranteed by the introduction of synthesizers for frequency control of both receiver and transmitter. In these clever devices a master crystal oscillates at a well-defined and constant frequency, which is multiplied and divided many times until, by adding the results, any frequency over a wide range is avail-

able kilocycle by kilocycle. Wide-band antennas (used a couple at a time to allow instant choice of the best path) and amplifiers are needed with this kind of equipment, and all the tuning becomes automatic and digital, even remote. The output is filtered, and only the necessary "side bands" are allowed to leave the antenna; the receiver is quite able to reintroduce the central frequency and sometimes even the central phase with accuracy, taking a phase cue from the last element received. Such "coherent detection" schemes can crowd a full 30 fast telegraph channels into one nominal voice channel.

Even this ingenuity has its limits; in a decade or so the high-frequency channels will be saturated. By then microwave dishes pointing to the invisible satellites will have taken up the world's heavy message burdens, but for a long time the thin antenna poles will still connect the out-of-the-way places of the world. Meanwhile those shifting tones you hear everywhere on the dial are full of meaning and emitted with insight. The plain text one can be less sure about!

SCIENTIFIC INSTRUMENTS IN ART AND HISTORY, by Henri Michel. Translated by R. E. W. Maddison and Francis R. Maddison. The Viking Press ($18.50). "By beauty of form I do not mean such beauty as that of animals or pictures, which the many would suppose . . . but . . . understand me to mean straight lines and circles, and the . . . figures which are formed out of them by turning-lathes and rulers . . . for these I affirm to be not only relatively beautiful, like other things, but they are . . . absolutely beautiful." So reads the epigraph out of Plato cited in this sumptuous volume. A hundred large color plates, made by a dozen photographers working the museums of Europe, are in this book. Its form was given it by Michel, himself not only a famous Brussels collector and an engineer of high repute but also a genuinely learned and original scholar in the field, author of the recent standard work on the astrolabe and ingenious solver of many historical puzzles. Here are displayed the instruments that speak for the growth of science: the weights and dividers, the waywisers and sextants, the clocks and the barometers and the microscopes. Most of the instruments were the ornaments of princes, the metal gilded and chased, set with silver and carved with foliage. Here they are almost always pictured against glowing backgrounds of rich cloth—gold, crimson or royal blue—that dominate the reader with an impression of luxury. This is a book for the coffee table or waiting room; it deserves a wide use in that shallow but agreeable mode.

But the book is worth much more than that. The photographs are not only beautiful but also clear; they show as well as a flat page and a single view can what you would see of these instruments in Florence or Paris or Nuremberg if you went to the museum with leisure and purpose. One page displays a handsome marine astrolabe, made of bronze innocent of ornament or gilt, used at sea to obtain star and sun altitudes, recovered from a wreck of the Spanish Armada. In another we see, housed in an elegantly decorated brass box, the square white rods of a set of "Napier's bones" made in Paris about 1617. The caption gives a very clear account of how these devices for multiplication were used. The entire text, informed and devoted, has two portions. For each class of instruments there is a brief introductory narrative essay, say on the history of astronomy or of drawing instruments. Then for each plate there is a long paragraph, sometimes accompanied by a diagram, that identifies the individual device and describes its construction, use and importance. Perhaps the most striking of the instruments is the oldest: the 3,000-year-old *pi*, a circular disk of amber jade used by Chinese savants to locate the celestial pole, around which the heavens and the earth turned. They did so by holding the disk as a template against the northern sky, fitting its edge to certain known stars. Then the true pole appeared in the center of a hole in the disk. At that time there was no pole star; precession had yet to point the earth's axis conveniently at a bright star to help the stargazer. This use of the *pi* has been worked out—it is perhaps not quite certain yet—by Michel himself. The book's last plate shows the first voltaic pile, a stack of green cloth disks and pairs of thin zinc and copper disks mounted in a utilitarian wooden stand.

This is a book that gains virtue from strongly personal taste and thought. It is not in itself a history of the instruments of science, but it is what every reader of that history needs and deserves: a great museum on paper. The translators have done a fine job, and they have supplied useful bibliographic aids.

EARTH PHOTOGRAPHS FROM GEMINI III, IV, AND V. National Aeronautics and Space Administration SP-129. U.S. Government Printing Office ($7). Most of the output of that huge publisher, the Government Printing Office, is given to either factual pamphlets, something like up-to-date hints on poultry diseases, or to prosy volumes of statistics or of testimony. Not this one. Here are some 250 pages in full color, without much text. The GPO has made us an album of snapshots in color taken by a number of talented amateur photographers. But these men aimed their Hasselblads with a difference. They were aloft 100 miles or more aboard one of the earlier Gemini capsules. Here are views of five continents (not the Antarctic) on the scale of a multivolume atlas. This is the scale for states, mountain ranges and river valleys. Sometimes the work of men appears. A ship and its wake mark with a black-and-white dash the blue page of a Pacific seascape. A forest fire can be seen, its white smoke distinct from the brushstrokes of clouds that are visible in most of the pictures. The delta and upper valley of the Nile are dark with water and life against the bright ocher of the desert—the signature of the work of men for 5,000 years. The Himalayas span the whole of a page, all crinkled snow; also to be seen are the Zagros Mountains, where men first learned how to farm. The familiar shapes of the maps are there: the Red Sea and the finger of Lower California, the long rivers cutting the Chinese plain, the narrow Pillars of Hercules. A lonely atoll lies like a loop of thread on the ocean. Even highways can be made out here and there when the light is just so.

The volume is only accidentally an atlas, but it is a stunning one; it deserves to be studied with a map atlas beside it. The editors do supply an index map, and they give full photographic and geographical data. No one who likes maps should miss the chance to see what the camera tells about the once symbolic world of the cartographer. School libraries in particular need this book.

THE STONE AGE HUNTERS, by Grahame Clark. McGraw-Hill Book Company ($5.50). Three new themes inform this compact and masterly review of our knowledge of how men came to be urban and civilized. First of all, there is the recognition, based both on theory and on the epochal finds at Olduvai Gorge, that there was a long time indeed—hundreds of millenniums—during which men rose from a primate stock of gatherers and finders to become a bold race of hunters, bearing fire and fire-hardened tools. The settled farming life arose in only 1,000 or 2,000 years, out of an advanced herd-hunting technology.

Second, there is increased recognition of the early importance of symbol. No

one ever doubted that speech, the base of man's power, was the property of such men as the cave painters of 20,000 years ago. Now we are beginning to see, through the work of André Leroi-Gourhan, discussed here, that their graphic legacy has a large symbolic content as well, a content that seems as much psychosexual magic as hunting magic. Nests of buried heads, painted with ocher and decorated with jewels, unite the earliest farming villagers with their European hunting contemporaries in a widespread culture we still know only dimly.

Third, the surviving hunting peoples are once again seen, as they were a generation ago, as guides to the history of all men. They are no longer held to be mere fossils of an ancient culture but rather men who exhibit under similar economic and demographic limitations the uniqueness and the commonalty of how men live. There is a picture per page in this fine small book, many in color as glowing as those of the Baltic amber bear and the Australian spearpoint worked out of bottle glass. Most of the illustrations are freshly chosen, although some imperishable classics are also here. Photographs of a hunter with spear-thrower raised and of an artist of Arnhem Land painting on bark show us living men whose intensity and evident power open a glimpse into the warmth behind those stones and bones that sit in the museum cases of the world.

QUASI-STELLAR OBJECTS, by Geoffrey Burbidge and Margaret Burbidge. W. H. Freeman and Company ($7.50). Up-to-date (all relevant data up to early 1967), personal yet comprehensive, this small book is as good as its authorship suggests. Roughly half of it is a clear and crisp summary of the facts about quasars (150 are listed, with 100 red shifts), their identity, spectral lines, optical and radio continuum and variations, and distribution in depth and direction. The other half is an excellent summary and critique, partisan but fair, of the models proposed to make order out of the properties of these bewildering objects. The conventional view that they are remote, dense, energy-rich galactic nuclei in some early stage of an explosive evolution, red-shifted by the universal recession, is given some hard blows by the authors. Why is there such a clustering of the absorption spectra at a shift near an indicated velocity of 80 percent the speed of light? Are they really distributed uniformly over the whole sky? Can they radiate so much light from such a small volume? Or is the red shift intrinsic, and are the quasars much closer and less energetic than the enormous distances implied by the Hubble relation? We do not know, the Burbidges agree. Ninety-five percent of quasar theories are wrong, they say. But we must admit alternatives even when they promise unpalatable surprises, since the quasars themselves are the biggest surprise since Hubble's work 40 years ago. That is their main conclusion. Only the "standstill cosmological" proposal—that the quasars preferentially show the red shift belonging to an ancient time, when most of them formed during a pause in the universal expansion—is too recent to be treated. In any case, it probably carries too heavy a burden of hypothesis for a small result. Perhaps the last word belongs for a while to the Burbidge's 10-year-old daughter, who calls them "crazy stellar objects."

IMAGES OF THE UNIVERSE. LEONARDO DA VINCI: THE ARTIST AS SCIENTIST, by Richard McLanathan. Doubleday & Company, Inc. ($4.50). Here is a bargain. The large pages of this not very thick book present a splendid selection of the drawings of Leonardo in their original size, most of them either from the famous *Codex Atlanticus*—that ocean of a volume—in Milan or from the Queen's rich collection in Windsor Castle. The book contains more than 120 drawings, clearly reproduced from the original silverpoint, chalk, pen-and-ink or woodcut. The original background paper of all the drawings is carefully reproduced in brownish tones. The most familiar examples are present: the embryo in the uterus, the male figure spanning a circle, the 27 cats and a house dragon. But there are many more that are less familiar: the courtyard of the cannon foundry, the cluster bombs pouring from the bombards, the marvelous studies of water jets, vortexes and waves. A brief, clear and unpretentious text adorns the drawings with its clarity and detail, its good sense and easy learning. It is fine to read how Leonardo kept a real dragon, a wall lizard that he fitted out with wings, horns, beard and false eyes, which "ran... up the walls..., its wings quivering as if it were about to fly."

AEROSPACE FACTS AND FIGURES, 1967, by Aerospace Industries Association of America, Inc. Aero Publishers, Inc. ($3). Latest issue of the annual statistical review of our largest manufacturing industry. Eighty percent of its sales were to Uncle Sam. Aircraft production is just half of the total, with civil aircraft most of that non-Federal 20 percent. Boeing, the biggest defense contractor, has averaged more than $1 billion a year in prime contracts since 1950. The U.S. military will operate about 11,000 helicopters by the middle of 1968, one in three of all their aircraft. The U.S. airlines are running about 2,300 planes, the most used model being the Boeing-727, with the Boeing-707 a close second. There are still 137 DC-3's in U.S. airline service. Nearly 30 percent of the aerospace workers in California and nearly 30 percent of all the scientists and engineers in the U.S. work for the aerospace industry.

GENERAL VIROLOGY, by S. E. Luria and James E. Darnell, Jr. John Wiley & Sons, Inc. ($12.50). The first edition of this penetrating textbook appeared in 1953, the year James Watson and Francis Crick found the double helix of DNA. Fully up-to-date and still within reasonable compass, this second edition manages to retain its old quality of mapping a forest of results while keeping visible the evidence from tree after tree. By now the definition of life with which both versions begin commits the authors to accepting a piece of bacterial DNA as living matter. The new photographs go far beyond the already splendid ones of 15 years ago; the phage particles can be seen spiked onto the bacterial wall as plainly as a mosquito poised on your wrist, and polyhedral herpes virus coats are as clear as pinecones.

WILD FLOWERS OF THE UNITED STATES, VOLUME II: THE SOUTHEASTERN STATES, by Harold William Rickett. McGraw-Hill Book Company ($44.50). Two weighty books comprise this "volume," which continues the lavish photographic display in color of our wild flowers. Here one can see and read of 1,900 species, among them a brilliant orange orchid of the Florida swamps, and that beautiful tropical intruder, the water hyacinth. Wild-flower enthusiasts from the Carolinas to the Gulf will somehow find access to this work.

THE MEANING OF EVOLUTION: A STUDY OF THE HISTORY OF LIFE AND OF ITS SIGNIFICANCE FOR MAN, by George Gaylord Simpson. Yale University Press ($2.45). At last thoroughly revised in detail, but only in detail, this justly influential book is now better than ever. It far surpasses the earlier abridged paperback editions, wherein the author "favored conclusions over evidence." He expresses his regrets and has given us this fine new paperback.

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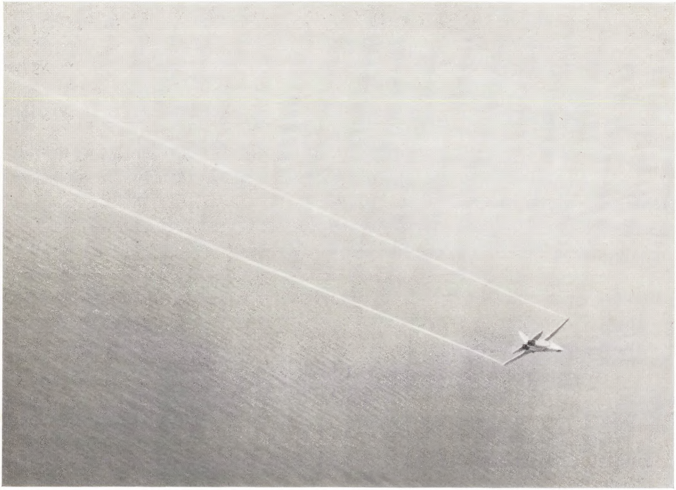

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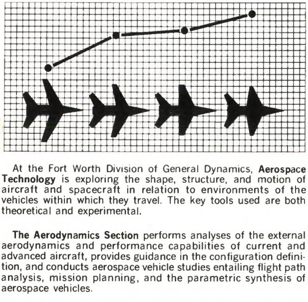

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